HYDROGEOLOGY OF THE NORTHERN PART OF THE UNITED ARAB EMIRATES

A Thesis

submitted for the Degree

of

Doctor of Philosophy

By

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CONTENTS

ABSTRACT

The northern part of the United Arab Emirates comprises an area of about 5000 square kilometres containing mountains and sand dunes separated by flat gravel plains. This latter unit contains green areas of gardens sustained by irrigation from ground water which provides some 60 percent of the agricultural produce raised in the United Arab Emirates.

The ground water occurs in a gravel-conglomerate aquifer in continuity with an underlying limestone-marl aquifer. Little information is available on the details of such aquifer characteristics as thickness and lithology. It is presumed that alternation of sand, gravel, silt and clay comprise the upper aquifer sequence, while the possibility of fissure flow in the underlying carbonate aquifer can only be inferred by comparison with similar strata in the mountain region.

The major gravel aquifer is unconfined with storativity values of the order of 10^{-2} and transmissivities ranging from 250 to 2500 m^2/d in the northern part but one order of magnitude less in the southern gravel plains. Yields from boreholes are variable, reflecting differences in hydraulic conductivity and the consistently high well losses due to incomplete development after drilling.

The water table slopes in a generally north-western direction with hydraulic gradients becoming less steep in the direction of flow with low velocities of less than 0·5 m/d confirming the pre-1954 tritium dating of the water.

The chemical quality of the ground water is generally poor with a TDS content increasing in the direction of flow ranging from less than 1000 mg/l to over 7000 mg/l.

The non-renewable resource is estimated to be about 3000 million m^3 with average replenishment of some 40 million m^3 per annum. Abstraction is

estimated to be of the order of 80 million m^3/annum so that the hydrological budget is in a condition of imbalance with depletion of permanent storage making inevitable the eventual exhaustion of the ground water resource if artificial supplementation is not undertaken.

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOPLATES

LIST OF ENCLOSURES

(folded in pocket at back of volume)

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1. INTRODUCTION

False-colour satellite photograph of northern U.A.E.

1. INTRODUCTION

The United Arab Emirates (UAE) form the south-eastern coastline of the Arabian Gulf, and consist of seven member states which are in alphabetical order, Abu Dhabi, Ajman, Dubai, Fujaira, Ras Al Khaimah, Sharjah, Umm Al Qaiwain. This coastal area has in times past been known as the Trucial States, Trucial Oman or even "Pirate Coast". The discovery of oil in the 1960's has provided a physical transformation with accompanying political and economic progress that has stretched the commonly accepted services to their limits. The population of the UAE according to the 1975 census was about 630 000 persons, having increased during the periods 1971-73 and 1973-75 by 178 percent and 193 percent respectively. As might be expected, the consumption of water has similarly increased with estimates of about 33 million cubic metres in 1973 currently being uprated to 139 million cubic metres - an increase of over 400 percent in four years.

1.1 Location:

The study area comprises the northern portion of the United Arab Emirates lying north of latitude 25° 15' north, and west of longitude 56° 10' east (Fig. 1.1) and includes the emirates of Ras Al Khaimah, Umm Al Qaiwain, and Ajman together with some parts of Sharjah emirate, and totals some 5000 square kilometres. The road that runs due east from Sharjah, via Dhaid to Masafi and beyond, provides an artificial though practical southern boundary for the triangular-shaped area investigated, while natural boundaries of coastline and mountain range respectively provide the western and eastern limits.

1.2 Topography:

The gross topographic divisions are simple and clearly delineated, though minor variants occur within each division. Salt flats with sand spits and islands border a narrow coastal fringe that rapidly passes eastwards into an area of dune sands. This in turn is fringed further inland by flat gravel plains which themselves are terminated abruptly by a precipitous mountain range that arises to heights in excess of 3000 metres. It is this combination of desert and mountain that directly and indirectly is both the consequence and cause of interesting hydrogeological features and water-use patterns.

1.3 Climate:

Tha United Arab Emirates lie within the hot, arid climatic zone where mean annual temperature and potential evaporation are consistently high. Rainfall may take place during the winter season and is generally meagre, though higher in the mountains than on the flat plains and sand desert to the west. The total annual rainfall is commonly less than 200 millimetres and often less than 100 millimetres. Relative humidity is low inland, but may be excessive along the coastal fringe. As might be expected of hot desert regions, the rainfall is not only sparse but demonstrates the extreme spatial and annual variation that supports the generalisation that "the lower mean annual rainfall, the greater annual variation and degree of unreliability" A more detailed study of the relevant climatic parameters is given in Chapter 4 (Hydrometeorology).

1.4 Vegetation:

Natural vegetation is sparse and stunted; consisting mainly of seasonal grass on the gravel plains, scattered thorn bush near the wadi areas, and low creeping plants that have a tendency to help stabilise the sand dunes.

Nevertheless, Ras Al Khaimah is known throughout the Emirates for the relative greenness of its scenery, and this is almost wholly due to vegetation that is sustained by irrigation water.

1.5 Land Use:

The pattern of development incorporates traditional and modern facets but exclusively avoids the mountain region which can be entered only along the dry wadi beds snaking their way between cliff-like walls. Urban development and its associated problems predominate around the major towns of Ras Al Khaimah, Ajman, Umm Al Qaiwain, and a number of smaller townships along the coastal fringe linked by the dual-carriageway. The gravel plains are fertile so that irrigation-supported gardens provide relatively extensive green areas contrasting with the undulating reddish-brown dune sands and provide a dramatic view.

1.6 Scope of the Investigation:

The main scope of the hydrogeological studies in the area investigated includes:

(1) a study of the hydrogeological characteristics and properties of the major lithological units in the area by reference to their occurrence, distribution, thickness, water-bearing and yielding capacities, and their hydraulic inter-relationship.

(2) determination of the direction and quantity of ground-water movement in order to determine replenishment zones.

(3) a study of the chemical quality of the ground-water and its suitability for domestic, agricultural and industrial purposes.

(4) assessment of the ground-water resources with special reference to their present state and future development.

1.7 Method of Investigation:

The duration of study has extended over four years with time spent working up material in London to fulfill residential qualifications alternating with leaves of absence in the United Arab Emirates to allow collection of further data.

The programme initially involved the collation of existing data, firstly from a number of reports referred to at different points in the succeeding text, and secondly from the various records held in the Ministry of Agriculture (Dubai), Agricultural Trials Station (Digdaga), Ministry of Electricity and Water (Dubai), the International Water Well Drilling Co. (Dubai), and the Ministry of Electricity and Water (Ras Al Khaimah).

After collation and analysis of such data, the next stage was the preparation of a provisional series of maps to illustrate the essential features of drainage, geology, aquifer systems, elevation of water levels, chemical quality and pumping well distribution. Some attempt was made to fill the inevitable gaps and deficiencies in the data distribution and quality by further observation and field work, along with an updating of older information. The author was fortunate in being able to persuade the Government of Ras Al Khaimah to undertake the programme of rigorous well testing which has ensured a quantitative basis for that part of the work dealing with aquifer properties.

The work aims at being a comprehensive account of the ground-water resources written from the viewpoint of the potential users and managers. It is recognised, however, that due to the combination of human and physical factors, many deficiencies in data quality and distribution will make somewhat hesitant the long term extrapolation of local results to the area as a whole.

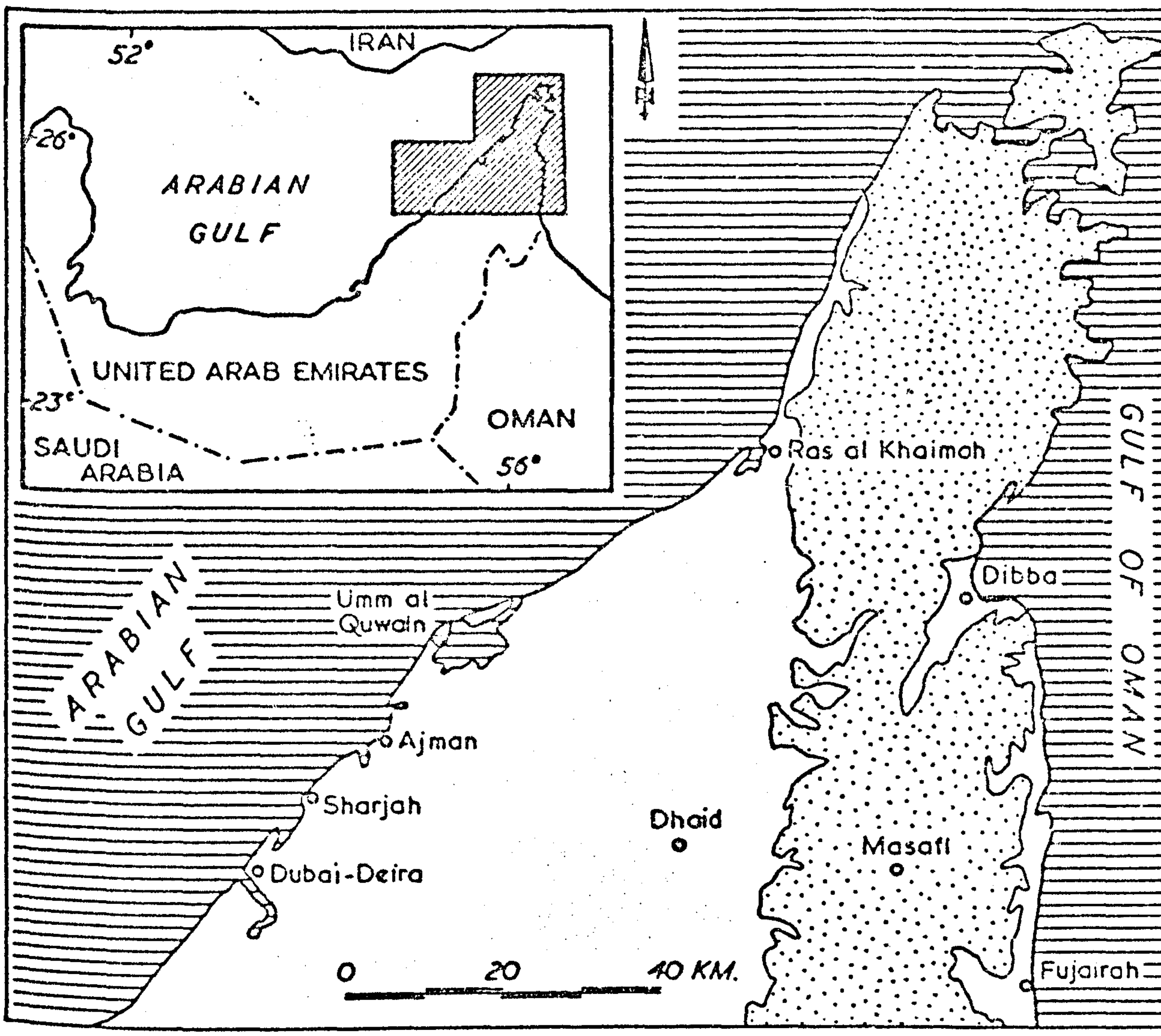

Fig. 1.1 Location map.

2. GEOLOGY

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2.1 INTRODUCTION AND PREVIOUS WORK

This study is primarily concerned with the geology of the northern part of the overall Oman Mountain range and those strata making up the plains to the west. Being an area of intimidating physical and climatic conditions with few tracks and a sparse (and sometimes hostile) population, it is not surprising that up until fairly recently the great bulk of geological information had been acquired by oil company geologists and their associates.

The earliest exploratory studies reported were those undertaken by G.E. Pilgrim of the Geological Survey of India at the turn of the century, but not until Lees (1928 a, b) was there an account of the geology of the Oman Mountains. Even then Lees had not been allowed to visit areas that subsequently became crucial to the interpretation of the stratigraphic and tectonic sequence of the mountain range. Little more was subsequently done until after World War II when in the period 1950 to 1960, geologists from the then Iraq Petroleum Company undertook extensive field work studies which were reported by Hudson _et al_ (1954), Morton (1959) and Hudson (1960) and differed in details of interpretation from that of Lees. Over the next decade, field mapping by Shell geologists added much knowledge of the geology of the mountain areas and was particularly significant for the evidence it provided in support of some of the original contentions of Lees. Tschopp (1967), Wilson (1969) and various publications by Glennie _et al_ (1970 and 1973) amplify the details of this essential difference. Butler _et al_ (1964) reported on the occurrence of anhydrite from the sabkha of the Arabian coast, while Greenwood and Loney (1968) and Crawford (1972) had concerned themselves with the geology of the Oman Mountains in the

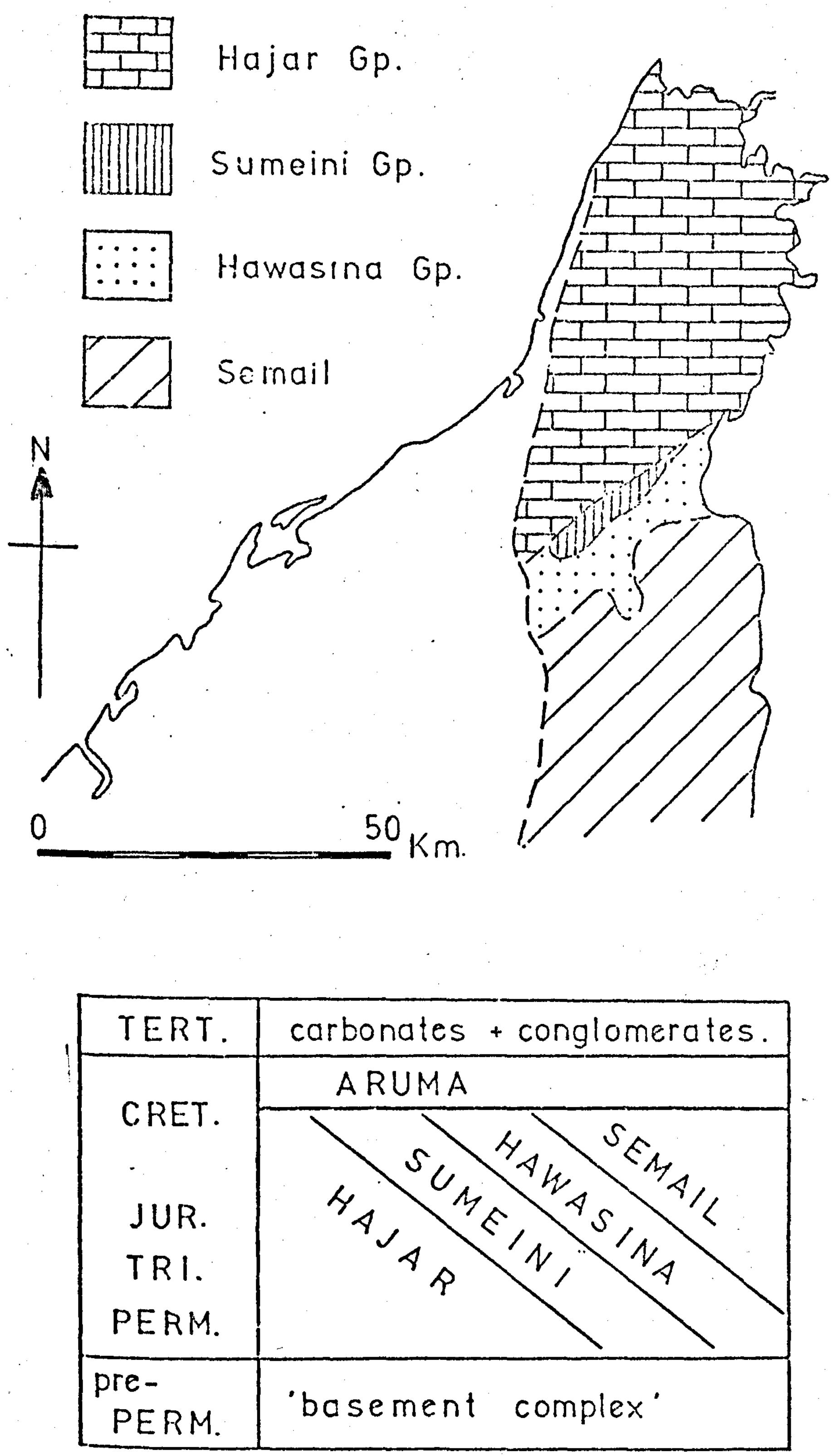


Fig. 2.1 Simplified geological map with sketch sequence

context of mineral resources and plate tectonics respectively.

The interest in and discussion stimulated by the geology of this small and remote corner of Arabia arises from the complex orogenic arc that has been formed at the edge of what is otherwise a stable shelf area. Lithologically, six major units are identifiable as follows:-

F : carbonates of late Cretaceous and early Tertiary age;

E : basic and ultra basic rocks assigned to the 'Semail' Group;

D : cherts, limestones and turbidites assigned to the 'Hawasina' Group;

C : local thrust sequences of limestone and dolomite, mudstones and conglomerate, conformably overlain by Cretaceous conglomerates and cherts, the unit being known as the 'Sumeini' Group;

B : limestones, dolomites and marls ranging in age from Permian to Cretaceous;

A : basement complex rocks.

The depositional sequences and subsequent tectonic complexities that may be deduced from the alternative interpretations regarding the interrelationships of these groups are of particular interest to general geology, petroleum exploration, plate tectonics and sedimentation, but need to be kept in proper perspective for water resources studies. It is the contention of this work that for ground water investigation purposes the geological history of the area is of less importance than the present distribution of the different lithologies which directly or indirectly affect ground water occurrence, movement and chemistry. The account of the geology will therefore be restricted to features considered relevant to subsequent sections of the work.

2.2 CONSOLIDATED LITHOLOGICAL UNITS

The simplified geological map of the Oman Mountain region shown in Fig. 2.1 with its diagrammatic sketch sequence demonstrates the essential features regarding the distribution of the previously mentioned units or groups

UNIT A: Basement Complex rocks do not outcrop in the study area, though to the south in Oman they consist of granites, gneisses and metamorphosed sandstones, limestones and volcanics attributed to pre-Permian age. These rocks form the framework upon which the subsequent deposits of the Arabian continental margin were laid down.

UNIT B: The dominantly shallow-water deposits that comprise the bulk of the sequence of this unit range from mid-Permian to Cenomanian in age and have been assigned to a number of groups as shown below:-

Cretaceous	Cen.-Alb. Apt.-Berr.	Hajar Super Group	Musandam Group	Musandam Fm.
Jurassic Triassic			Elphinstone Group	Ghalilah Fm. Milaha Fm.
Permian			Ruus Al Jibal Group	Ghail Fm. Hagil Fm. Bih Fm.

The Hajar Super-Group comprises three groups all representing shallow-water conditions that range in age from Permian to Cretaceous and is restricted to the north of the Dibba fault zone. The oldest is the Ruus Al Jibal Group consisting of three formations of Permo-Triassic age which is equivalent to the Permian strata of Elphinstone Inlet (Lees, 1928) and at the type locality in J. Hagab is some 1500 m thick. The lowest Bih Formation is made up of dark brown to grey dolomite with a distinct bed of limestone conglomerate and is regarded as ? Permian in age. Its base is nowhere exposed, and is regarded as tectonic. The formation was originally defined by Hudson *et al* (1954 a) and Hudson (1960) from W.* Hagab for the much-burrowed, thickly bedded, dolomite with occasional intercalations of partly dolomitised or porcellanous limestones. Although 650 m of the formation have been reported from J. Hagab, only 200 m is exposed in the type locality at W. Ghail within the Bih anticline near Ras Al Khaimah. This formation is conformably

* abbreviations: W = wadi; J = Jebel

overlain by the Hagil Formation described by Hudson (1960) from the W. Ghail where 260 m thickness is exposed in the east and south sides of the Hagil 'window'. The Hagil Formation consists of light-coloured, fine grained argillaceous limestones with shale partings and occasional shale beds, dolomitised limestones and slightly oolitic limestone. The latter yield foraminifera of Permian (? Triassic) range. The uppermost of the three formations is the Ghail Formation, described by Hudson et al (1954 a) and Hudson (1960) from the type locality at W. Ghail where some 500 m conformably overlies the Hagil Formation. It consists of thickly-bedded, grey to buff coloured dolomite and dolomitic limestone, with a massive dolomite at the top of the formation forming a topographic marker horizon with a cliff face. The sparse fossil content suggests that the formation is probably Triassic in age.

The Elphinstone Group was defined by Hudson (1960) from the type locality near J. Hagab where some 450 m of dolomitised limestone yields a fauna indicative of mid to late Triassic age. The group is equivalent to the Elphinstone Beds of Lees (1928), and consists of two formations. The lower Milaha Formation takes its name from the W. Milaha to the south-east of Ras Al Khaimah where a soft-weathering, brown siltstone and reddish, nodular dolomitised limestone passes up into well-bedded, more massive, buff dolomite with chert nodules, and is topped by dark grey shelly limestone. This sequence is conformably overlain by the Ghalilah Formation which in W. Milaha shows 255 m of strata that is distinguished by occasional quartzose sandstones, representing a regional clastic influx from the west into a dominantly carbonate environment. Limestones with limestone conglomerate, quartzose sandstone and siltstone pass upwards into limestones and dolomites that are devoid of quartzose sandstone, but are in turn overlain by a limestone-shale member with further quartzose sandstones and topped by a ferruginous oolite.

The youngest group of the Hajar Super Group was defined by Hudson et al (1959) as the Musandam Group for the extensive limestone succession of Jurassic to Lr. Cretacous age that covers most of the Musandam peninsula and is equivalent to the Musandam Limestone of Lees (1928). In the type area, a monotonous sequence of dark grey shallow-marine carbonates totals some 1475 m in thickness. In the study area to the north-east of Khatt, the lower part of the Musandam Limestone conformably overlies the Elphinstone Group in an 860 m thick sequence consisting of a variety of pale coloured limestones ranging from oolitic, skeletal, pelletal to bioclastic, in thickly bedded to massive units.

UNIT C: The localised thrust slices of this unit have been named as the Sumeini Group and were considered by earlier workers to be part of the Hawasina unit. In defining it as a separate group, Glennie et al (1974) suggest that it is the time equivalent of both the Hajar Super Group and the Hawasina and was actually deposited between those two time equivalent areas of deposition. The base of the Sumeini Group is always a tectonic surface, and it comprises four distinct formations, as tabulated below:

Age	Formation	Lithology
Jur to mid-Cret.	Mayhah Fm.	slumped and congl. sandstones and mudstones with minor red chert
late Triassic?	Maqam Fm.	argillaceous mudstones interbedded with conglomerate
late Triassic	Jebel Wasa Fm.	whitish coarse boundstone
Permian to late Triassic	Ramaq Fm.	limestones, dolomites, sandstones and marls

There is no locality where all four formations can be found together; the Ramaq Formation is at least 1600 m while the Maqam and Mayhah formations together total a similar thickness. In the study area rocks of this group are not found north of the Dibba fault area.

UNIT D: The Hawasina Group is also known as the Hawasina Complex and is equivalent to the Hawasina Series of Lees (1928). It forms a tectonic and stratigraphic complex that is divisible into eleven tectonically bounded lithostratigraphic units that everywhere retain the same order of superposition. The sequences are commonly folded into structurally complex forms, and although it is not possible to determine the original thickness of a stratigraphic sequence, the sum of all the tectonic sheets would exceed 3000 m. The type locality occurs in Oman, well to the south of the study area, where the bulk of the Group appears to have been deposited as turbidites in relatively deep water. In the study area, rocks from the Hawasina Group are, with one exception, restricted to the Dibba fault area where two of the fault bounded sheets have extensive outcrops. The apparently lower Dhera Formation contains a flysch-like sequence of limestone turbidites, conglomerates and occasional green or red, bedded chert. Both lower and upper contacts are tectonic, though microfossil evidence suggests that deposition took place throughout the late Permian and Triassic, and ranged upwards via known early Jurassic forms to early Cretaceous. The Dibba Formation has an obscured tectonic lower boundary on the Dhera Formation in the Dibba fault area where some 500 m of a dominantly carbonate sequence is nearly fully exposed. A lower member of oolitic limestones and dolomitic mudstone passes up into one consisting of radiolarian chert and limestone with igneous clasts. An upper member, over 200 m in thickness, consists of oolitic limestone passing upwards into silicified limestone and chert with many conglomeratic horizons that contain derived limestone pebbles of Permian age. Another distinctive feature within the upper member is the presence of volcanic rocks (sills and flows) as well as volcanic fragments in the previously mentioned conglomeratic horizons. The age of the formation spans Triassic (?) to mid-Cretaceous time, and Glennie et al (1974) have therefore suggested that the Dibba and Dhera formations may grade into one another and be time equivalents.

The existence of up to 200 m thickness of red and green radiolarian cherts with mudstones, tuffs, basic lavas and igneous clasts was noted by Hudson et al (1954) in the Hagil 'window'. They named the sequence the Shamal Formation, identifying it on faunal evidence as Triassic to Cretaceous in age.

UNIT E: The term 'Semail' had been adopted by Lees (1928) and accepted by Morton (1959) for the large masses of basic and ultrabasic rocks that overlie the pre-Maestrichtian sediments and are in turn overlain by carbonates of Maestrichtian age. The essential difference in interpretation is that Morton believed the suite of igneous rocks to have been extruded more or less 'in situ' on a large scale during the Upper Cretaceous, whereas Lees, supported subsequently by Glennie et al (1974), considered the whole unit to have been thrust in the form of a great nappe from the east against the Arabian shield foreland. Depending on one's viewpoint the unit can therefore be described as Semail Nappe, Semail Group, Semail Ophiolites or Semail Complex, and there is no disagreement on the nature of the constituent rocks, or their geographical distribution.

To the south of the Dibba fault area and occurring neither within that area nor the Musandam peninsula to the north, is a complex but very distinctive suite of ophiolites that range upward in the form of mappable units from ultrabasic rocks (periodotites and serpentinites), via basic rocks (gabbros and fine-grained varieties with ophitic textures) and diabase dyke swarms to extrusive rocks (spilites, breccias and basalts). From the nature of the rock suite, its association with older and younger Cretaceous strata, and the regional reconstruction of the sedimentological and tectonic environment, Glennie et al (1974) interpret the 'Semail' as a piece of Mesozoic oceanic crust that was torn away and thrust westward in the form of a great nappe during late Cretaceous times.

UNIT F: In the study area, small remnants of Upper Cretaceous carbonates unconformably overlie strata of the Hajar Super Group amd are regarded as belonging to the Aruma Group. This lithological unit is known throughout the 'Gulf' area, and in the area of interest is divisible as tabulated below:-

Maest.	Simsima Fm.			Aruma
Camp.		Juweiza Fm.		
Sant.	Fiqa Fm.			Group
Con.			Muti Fm.	

Although well developed in Oman, outside the study area, the Muti Formation is restricted to three separate locations of small size; two in the Dibba fault area and the other in the Hagil 'window.' It consists of a flysch-like sequence of limestone conglomerates passing upward into turbidites, cherts and shales. The formation has been assigned a late Cretaceous (Coniacian to Late Companian) age and is distinctive in having no basic igneous clast content. Morton (1959) considered the formation to be an integral part of his 'Hawasina Beds', and regarded the fact that the Muti Formation deposits intertongue with the Upper Cretaceous 'globigerinal' marls (Fiqa Formation) of the foreland as important confirmation of his view of the 'in situ' nature of the Hawasina Group. Glennie et al (1974) exclude the Muti Formation from the Hawasina (Unit D) and by assigning it to Unit F, use the evidence of intertonguing to date the time of the nappe emplacement. The marls and shales of the Fiqa Formation (Senonian or Maestrichtian) to the west of the mountains grade laterally into the flysch deposits of the Muti Formation, but also into the flysch deposits of the Juweiza Formation. No outcrops of the latter have been identified and its type section is taken from exploratory well Juweiza I drilled in 1957, which passed through nearly 300 m (probably with some

Fault repetition) of marls, shales, breccias and conglomerates. Their age is from Campanian to Maestrichtian, and as basinal marls with coarse detrital debris the Juweiza and Muti formations have much in common besides their partial time equivalence. Where they differ is that the Juweiza Formation has in its conglomeratic horizons abundant chert and much basic igneous detritus. In the type well section the top of the formation is eroded and overlain by Quaternary gravels, though from nearby outcrops it appears as if shallow-water Maestrichtian limestones of the Simsima Formation would conformably overlie the Juweiza Formation. Southwest of the mountain range and passing into the western UAE, numerous boreholes associated with petroleum exploration and development have proved the existence of the standard Tertiary carbonate sequence that is well known throughout eastern Arabia and the Gulf area. Limestones and dolomites of the Ummer Radhuma Formation (Palaeocene - Lr. Eocene) are conformably overlain by limestones, anhydrite and marls of the Rus Formation (Middle Eocene), which in turn are overlain by limestones, shales and marls of the Dammam Formation (Upper Eocene).

A separate sequence in the southern part of the study area is highly relevant to the hydrogeology but is not easily attributed to one of the units previously considered. Along the western margin of the mountain range and extending continuously southwards from Idhn is a sequence of chert, dolomites and boulder beds that total some 200 m in thickness. The strata are not well exposed as a sequence and anomalies in their age and stratigraphic position have led to different interpretations.

Glennie et al (1974) tentatively proposed that a new informal unit known as 'Silicified Crust' should be applied to the crust of red-brown, hard, silica-rich rock (birbirite) that grades down into unaltered serpentinite and is always overlain by diagenetically altered gravels consisting of serpentinite fragments. They interpret the birbirite as an alteration

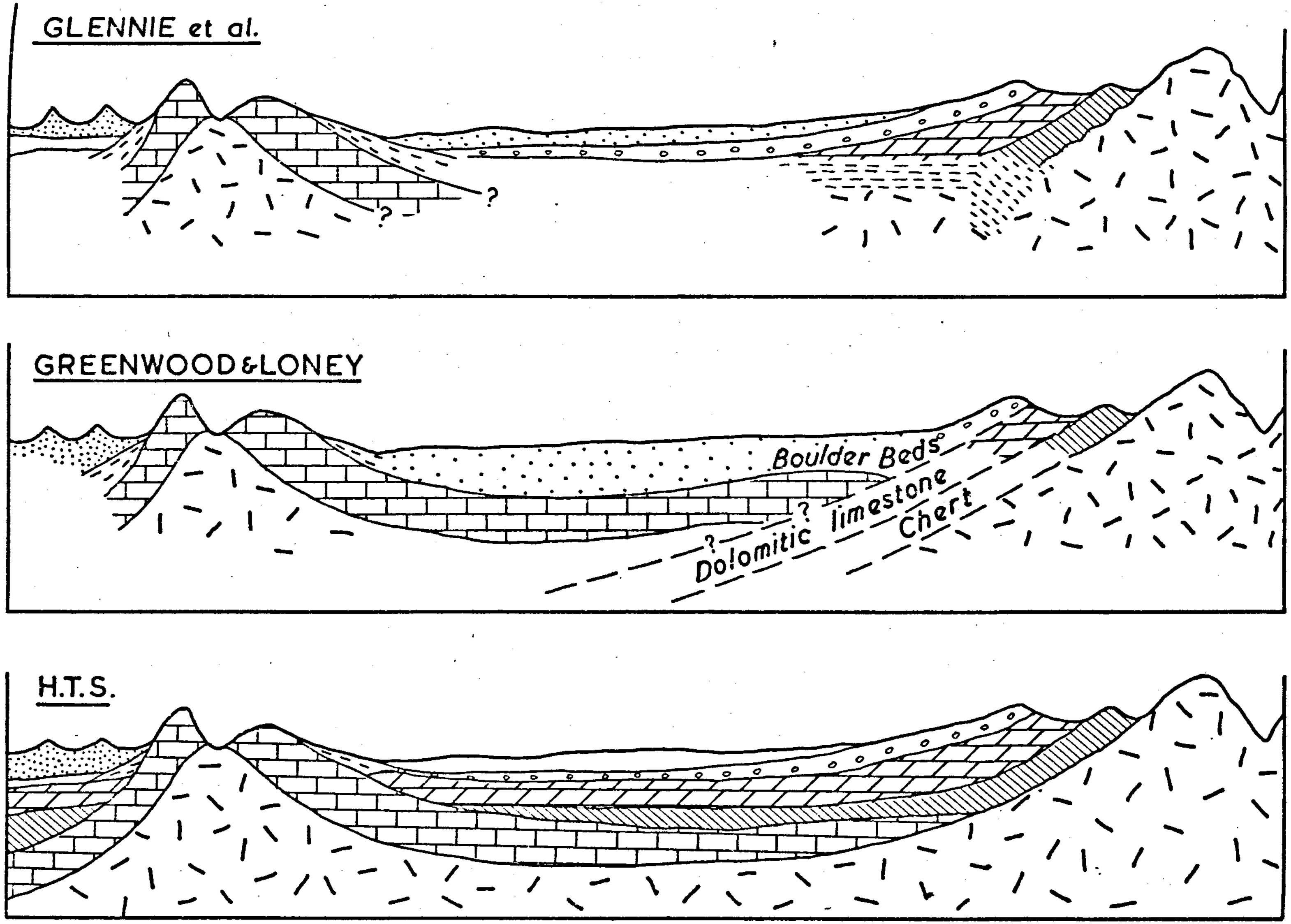


Fig. 2.2 Alternative interpretations of stratigraphical sequence near Dhaid in gravel plain area

product of serpentinite formed by selective leaching of magnesium associated with a fluctuating water table in Late Tertiary to Recent times. They further claim that the overlying gravels have in part been replaced by a massive rock unit consisting predominantly of dolomite with traces of silica.

Greenwood and Loney (1968), on the other hand, identified three distinct units as follows:-

unit	thickness (m)
Boulder Beds	<20
Dolomitic Limestone	80 - 100
Chert	100

and Hunting Technical Services (1975) agreed with the unit identification but disagreed with the interpretation of the stratigraphy in its relationship with adjacent strata of known age. Thus the former regard the triple-unit sequence as underlying nearby Maestrichtian limestones while HTS consider the sequence to be Tertiary in age and overlying Maestrichtian limestones.

The sketch sections in Figure 2.2 illustrate the alternative interpretations which it is clear will only be resolved by borehole drilling. For the sake of convenience, the sequence will be referred to as ?Cretaceous/ Tertiary in age and considered as part of Unit F.

2.3 UNCONSOLIDATED LITHOLOGICAL UNITS

There are three major lithological units that give rise to the distinct landform features described in Chapter 3, but also in their different ways play an important part in the hydrological regime of the area. These superficial deposits are regarded as having a Pleistocene to Recent age, and their thickness and occurrence varies widely over the area investigated. They may best be considered in the context of the condition of their formation as follows:

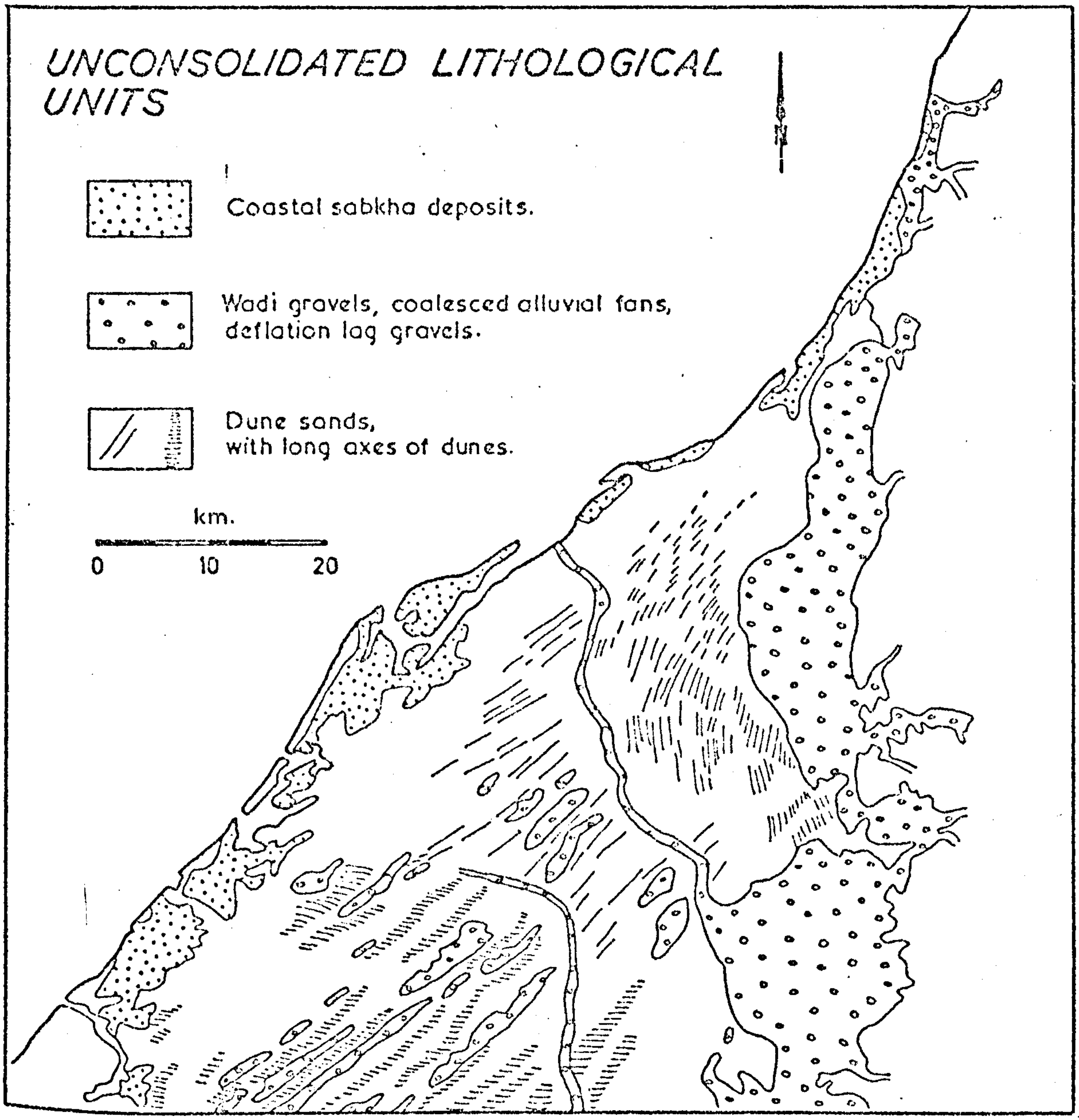


Fig. 2.3 Distribution of superficial deposits

conditions		deposits
tidal	sabkha	carbonate muds with anhydrite, gypsum and dolomite
terrestrial	eolian	dune sands; deflation gravels
	fluviatile	wadi gravels; alluvial fans

Fluviatile deposits: The more important of the water transported deposits are the wadi gravels and their associated sands and silts. Bearing in mind that the present climatic conditions are probably more arid than those of times past, it is likely that there would have been seasons and occasions when rainfall was sufficient to sustain streamflow at greater frequencies than present. Much of the sediment found in wadi channels has been deposited under normal fluviatile conditions with a braided-stream pattern of sedimentation that is typical of a reduction in the flow velocity of heavily-laden streams as they debouch from mountain regions over gently sloping alluvial plains.

The net result in the area of interest has been the production of a blanket of variable superficial deposits derived and extending westwards from the mountain range. They include 1) mudflow conglomerates produced by sheet flooding in an alluvial fan environment, 2) wadi channel conglomerates, thin cross-bedded sands, and cross-bedded conglomerates of the braided-stream environment, and 3) laminated sands, silts and clays of the flood plain environment.

The migration of distributary channels with a tendency to cut across intervening areas in times of overflow has ensured a complexity of lenticular deposits that make impossible the correlation of individual horizons. There is frequently a tendency to judge the nature of underlying deposits from those exposed at the surface, and in the northern UAE, as in other arid regions, this could be misleading. For example, the boulder-strewn surfaces

Photo. 2.1: Wadi gravels consisting largely of limestone cobbles and pebbles.

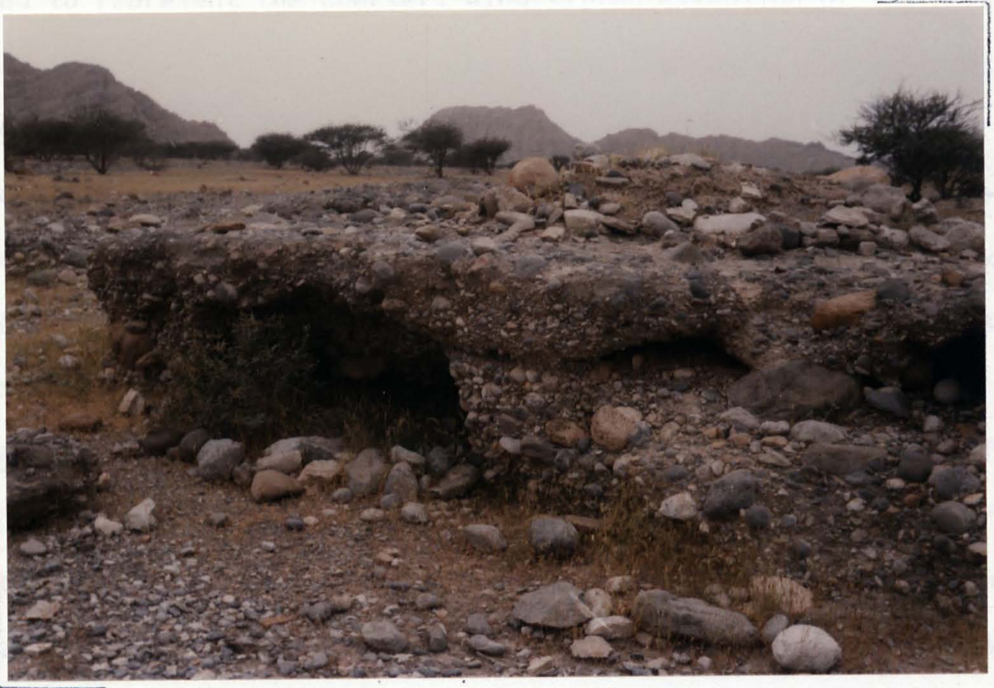


Photo 2.2: Differential cementing in alluvial gravels on plains to west of mountain range.

of the major fans and coalescing alluvial gravels are deflation features due to the removal of finer grained silt and sand by wind action (Photo.2.1).

In arid or semi arid regions, partial cementation of gravels can occur soon after deposition, particularly with water and materials derived from limestone areas such as that extending north from Idhn. With evaporation of water, the calcium carbonate in solution is precipitated at points of contact, though there is frequently an uneven distribution of cementation, both laterally and vertically, as illustrated in Photograph 2.2.

Eolian deposits in the area of study consist primarily of dune sands and isolated areas of deflation lag. The dune sands are composed of carbonate or quartz grains, and the dunes are commonly of the 'seif' type which have their axes parallel to the dominant wind direction. Deflation lag gravels which may extend over several square kilometres tend to have a NE - SW orientation and are separated from each other by large intervening seif dunes of Pleistocene age (Fig.2.3). These gravels or 'feidjes' are presumed to represent the coarser, wind-sifted extension of the gravel plain material with the inference that eolian conditions are in the process of masking the remnants of former drainage systems. It is interesting to note in Figure 2.3 that whereas the older, stabilised dunes have a NE - SW orientation, these are now superimposed by small seif dunes with axes at right angles to those of the larger dunes from which they derive most of their material.

Sabkha deposits may be seen from Figure 2.3 to fringe most of the coastline, where together with sandbars, spits and lagoons they form a distinctive environment (Photo. 3.8). The coastal strip has a complex outer zone of offshore islands, lagoons, channels and bars, and an inner zone of intertidal flats which pass imperceptibly into a supra-tidal, salt encrusted plain called the 'sabkha'. The sediments of the sabkha

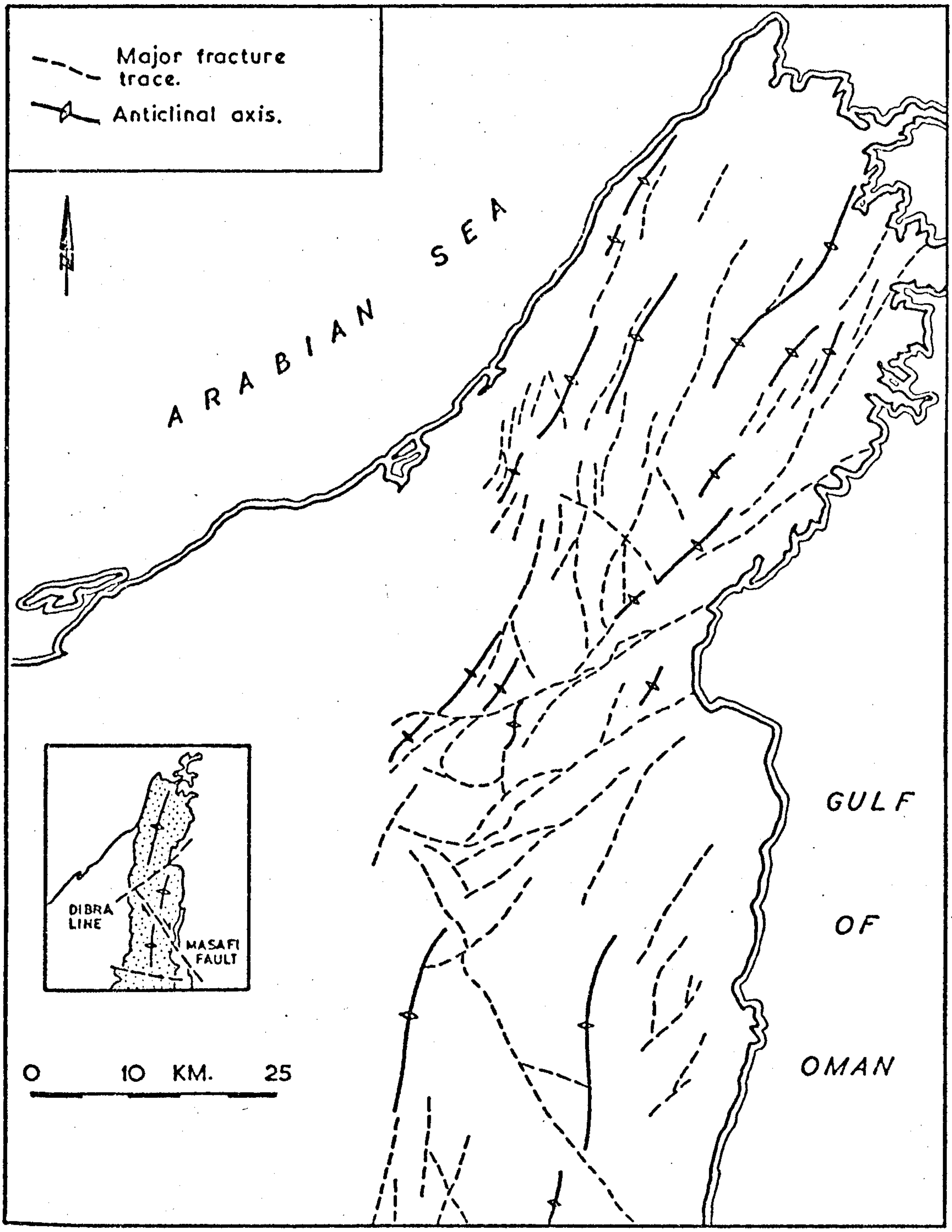


Fig. 2.4 Major structural features

surface consist mainly of carbonate muds, though a characteristic feature is the occurrence of nodular anhydrite, gypsum and dolomite (Shearman, 1966).

Evans et al (1969) reported the results of radiocarbon dating of thirty six samples, and interpreted the geological history of sabkha sedimentation in the UAE as follows:-

3750 BP	:	apparent fall in sea level with intertidal and supratidal sedimentation replacing subaqueous deposition;
4000 - 7000 BP	:	rise of sea level with flooding and erosion of Pleistocene dune sands;
pre 7000 BP	:	late Pleistocene and Holocene sedimentation dominated by eolian sand deposition.

The apparent fall in sea level was considered to be due to the result of reduced tidal range and wave heights at the shoreline produced by the growth of offshore islands, bars and reefs, rather than due to eustatic changes. However, in the vicinity of Ras Al Khaimah the pattern is complicated by sub-Recent tectonic movement with both elevation of marine terraces and subsidence to give drowned coastlines. The hydrological significance of the sabkha is considered in more detail in Chapter 6.

2.4 GENERAL STRUCTURE AND GEOLOGICAL HISTORY

The inset to Figure 2.4 gives for ease of understanding an overgeneralisation of the major structural features in the area of study. That the reality of the situation is more complicated can be judged from the additional details shown in Figure 2.4 . Nevertheless, the simplification serves to indicate that two zones of faulting separate the mountain region into discrete blocks or units. The Masafi fault line is less significant than the Dibba fault line which is the major fracture belt in the study area. It might be better described as a fault zone area since it contains numerous thrusts bounding a variety of Hawasina formations. The more detailed version shows clearly that to the north of the so-called 'Dibba Line", major fractures and fold axes are

Photo. 2.3: Steep dip of well-bedded limestones from Hajar Super Group along western edge of mountain range.

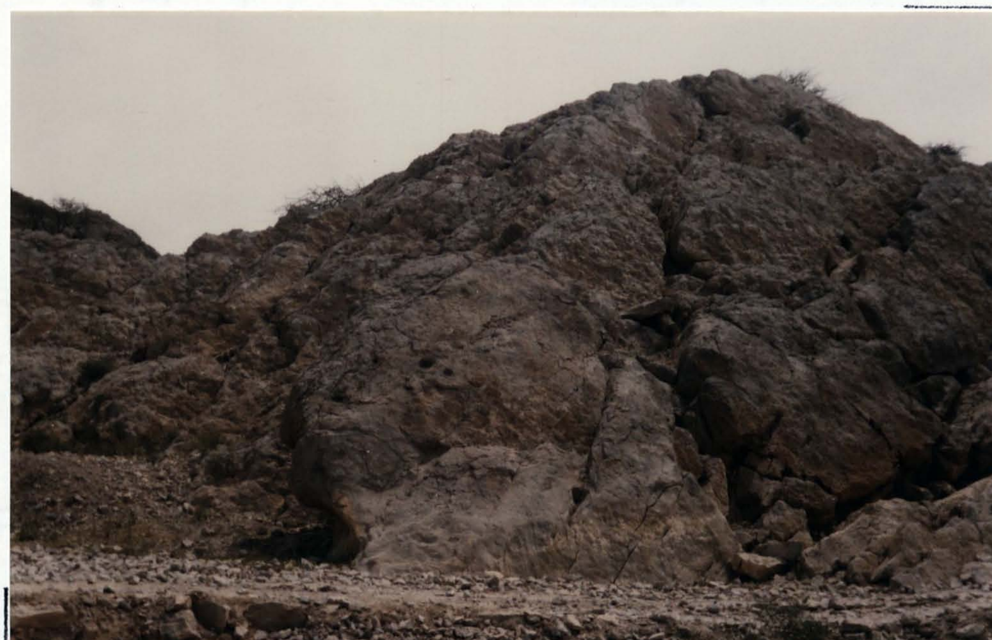


Photo. 2.4: Sheared and fractured strata in Hawasina rocks of Hagil 'window'.

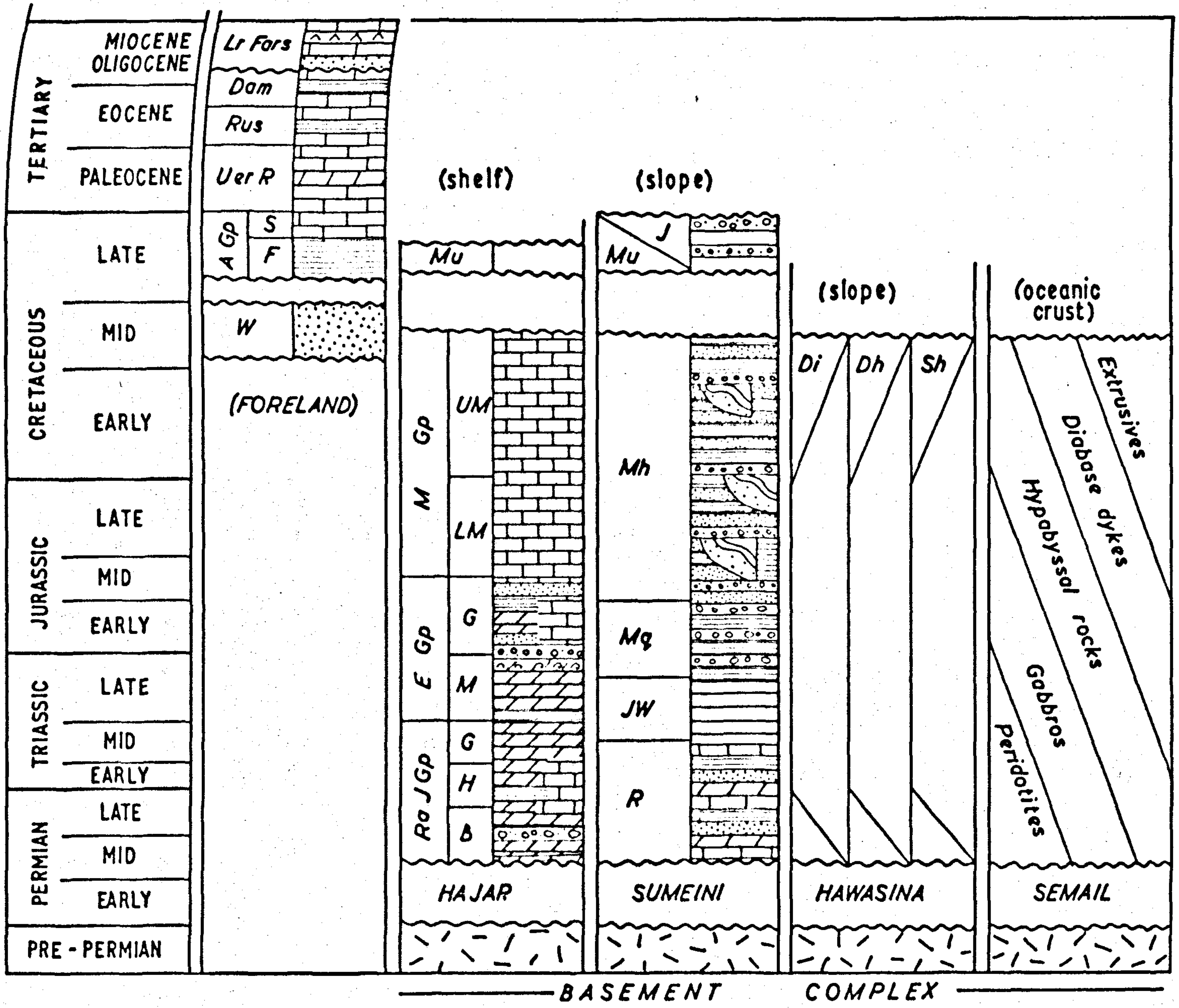


Fig. 2.5 Graphical summary of geological history

Photo. 2.5 : Sandbars, spits and lagoons forming the distinctive sabkha environment.

both oriented NNE - SSW, whereas in the 'Semail' and 'Hawasina' rocks to the south, fold axes tend to be orientated N - S with fracture traces having an ENE - WSW direction.

Most periods of geological time from the Permian up to the Recent are represented and Figure 2.5 summarises the details of the sequence of events in graphical form. In concluding this chapter the predominant feature to be remembered is the distinction between the rocks to the north and south respectively of the Dibba fault zone.

3. MORPHOLOGY AND SOILS

3.1 LANDFORMS

Mountains

Gravel Plain

Sand Dunes

Coastal Fringe

3.2 SOILS

Occurrence

Infiltration potential

3. MORPHOLOGY AND SOILS

3.1 LANDFORMS

The area under study may be conveniently divided into four morphological units, most of which are capable of further subdivision. These major physiographic units to a large extent determine the agricultural potential thatis feasible in terms of suitable land and water, and thus are likely to play a significant role in ground-water resources development and management.

The extent of the units and their subdivisions is illustrated in Fig. 3.1, tabulated below and described in turn.

Unit		Sub-division
1	mountain	a) north b) south
2	gravel plain	a) north b) south
3	sand dunes	-
4	coastal fringe	a) tidal flats b) sabkha

3.1.1 Mountain unit: The backcloth of mountains that enhance the appearance of the town of Ras Al Khaimah are part of a range of mountains that stretch southward from the Straits of Hormuz to form the spine of the Oman peninsula. The range varies in width in the study area from about 5 to 30 km, and is rugged throughout, with a maximum elevation of 2081 metres at a distance

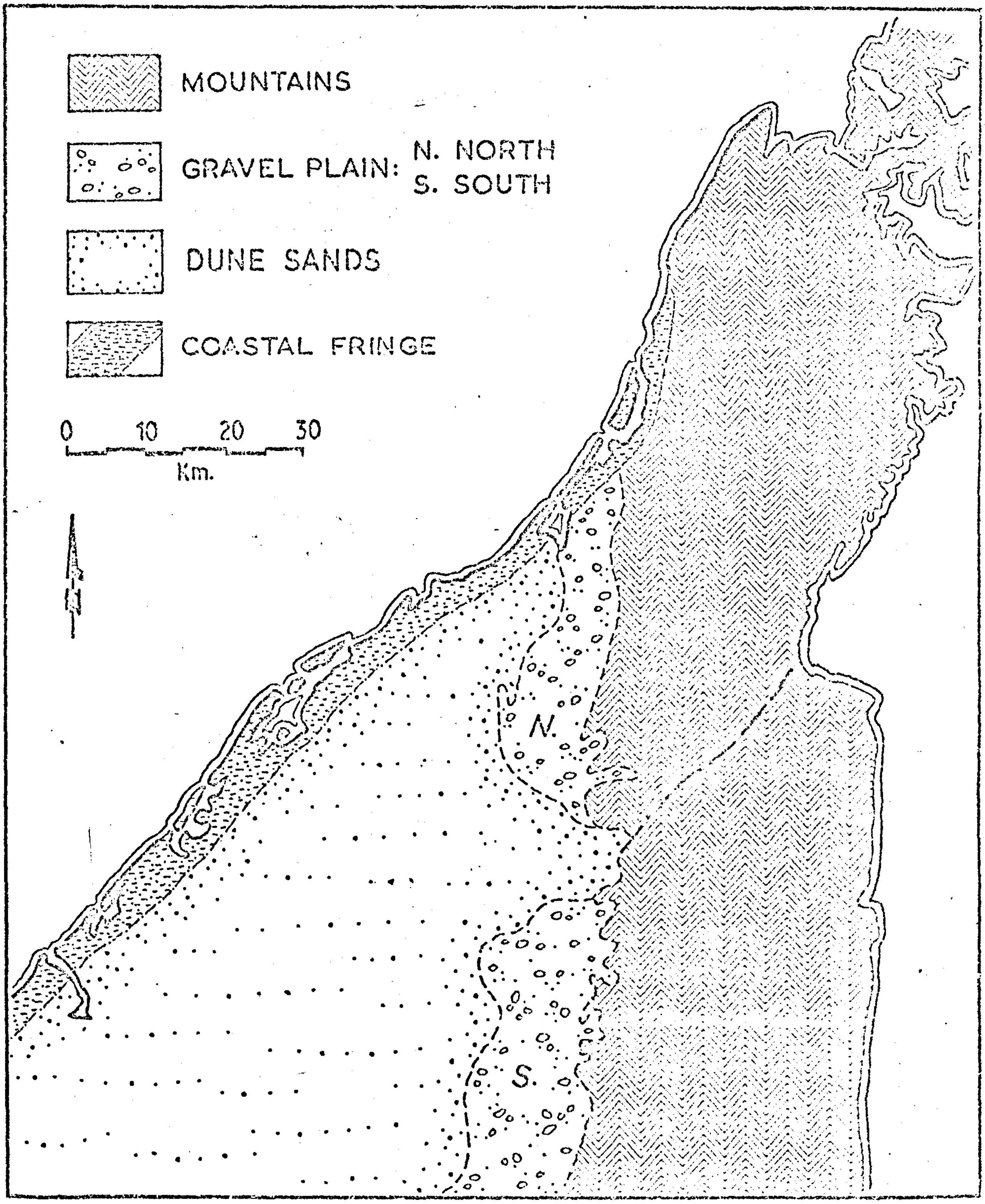


Fig. 3.1 Physiographic units

Photo. 3.1: Flat wadi floor bounded by steep sides.

Photo. 3.2: Wave-cut terraces along western margin of mountains.

of only 15 km from the coastline. The Dibba fault line referred to in the previous chapter has physiographic as well as geological significance since it serves to divide the mountain range into northern and southern sub-divisions.

The northern part is developed on limestones, dolomites and marls and extends northward into the Musandam Peninsula, though the name Ruus al Jabal is probably more applicable to the unit as a whole. The relief is extremely variable, frequently precipitous, and largely inaccessible even to four-wheel drive vehicles except via the major structurally-controlled wadis. Such wadis commonly have flat beds strewn with boulders and are flanked by steep sides that frequently are of cliff-like proportions (see Photo. 3.1). The degree of erosion and related tectonic uplift may be judged by the paucity of reasonably level land for development within the mountain or highland unit. Although the underlying geology is dominantly carbonate in nature, there is negligible evidence of any significant karstic development of the traditional kind with sink-holes and collapse features.

Given such tectonic complexity it is not surprising that evidence for differential vertical movement is to be found in such land forms as 'ria'-type coastlines with lengthy, steep-sided, drowned inlets contrasting with wave-cut terraces to be observed at heights of about 100 m and more above present sea levels the western mountain margin (see Photo. 3.2).

South of the Dibba fault-line the mountain range is developed on the thick sequence of metamorphic, ophiolitic and radiolarite series that have been much complicated by frequent large and small scale tectonic activity. The relief of this part of the mountain 'spine' is less pronounced than that farther north, with a maximum elevation of less than 1000 metres. Probably more important from a hydrological point of view is the more subdued topography that appears to reflect a uniformity of erosion despite the varied lithology. Related to the mountain range deposits but lying some 10 miles to the west are the isolated hills such as Jebels Faiyah and Mileiha which play a

Photo. 3.3: Wave cut platform at 300 m above sea level.

Photo. 3.4: Flat surface of gravel plain.

hydrological role far greater than their size would indicate, and which will be considered in more detail in Chapter 6.

3.1.2 Gravel Plain unit: With the exception of a break coincident with the Dibba Fault line, a gravel plain more or less continuously fringes the western side of the mountain range from near Ras Al Khaimah in the north to the south of the study area over a length of some 100 km (see Fig. 3.1). The surface of the plain appears flat or gently undulating (Photo 3.4) and the unit ranges in width from less than 10 km to over 20 km. In detail, however, the plain is far from featureless and contains numerous braided gravel-filled wadis with a dominant west-east direction that have cut into recent alluvial and terrace deposits. The wadis are commonly dry but in the same way that the plains were formed by outwash deposits from the mountains, so the present day 'flash' floods represent the accumulated run off from the same region. A general reduction in particle size from boulder-sized fragments in the east adjacent to the major mountain wadis to granule-size or less in the west, together with an increase in the proportion of sand and silt reflects the provenance of the material. This is more forcibly demonstrated by the contrast in fragment lithology in different parts of the plain. Thus the deposits of the Jiri Plain in the north are dominantly derived from the limestones and dolomites of the northern mountains while those of the Dhaid and Gharif plains in the south consist largely of metamorphic and basic igneous rock-fragments.

A significant feature of these plains are the areas of silt that appear to have accumulated at the western margins as a result of obstruction to surface flow of silt-laden flood waters.

3.1.3 Sand dune unit: A large part of the desert foreland consists of dune sands composed of two main varieties, either carbonate or quartz, the latter tending to be present in inland regions whereas the former have a coastal affinity. The dunes are dominantly aligned in a NE - SW direction,

Photo. 3.5: Sand dunes fixed by vegetation.

Photo. 3.6: Small closed depression within dunes with interior drainage.

Photo. 3.7: Narrow coastal plain between sea and mountain front.

Photo 3.8: Tidal lagoons and sand spits with associated sabkha deposits.

as is superbly illustrated in the frontispiece LANDSAT composite photograph. In the northern part of the triangular area formed with Dubai, Jebel Faiyah, and Ras Al Khaimah as the extremities, the dunes are commonly small and frequently fixed by vegetation (see Photo. 3.5). However, the dunes appear to increase in height towards the south where vegetation is largely absent and the winds stronger.

Common to the unit area as a whole are isolated pockets of closed drainage, and occasional gravel flats of greater extent that are nowadays separated by extensive dune systems from the gravel plain but were probably former continuations (Photo. 3.6).

The evidence from vegetation patterns observed on aerial photographs suggests a number of former wadi courses extending in a westerly direction towards the coast (Halcrow, 1969, p.24). However, at the present time for the area under study, the sand dune unit is crossed by only one wadi, the Wadi Lamhah, which occasionally carries surface runoff originating from the Dhaid-Gharif Plain to reach the sea at Batha al Ali.

3.1.4 Coastal fringe unit: The land margin along the Arabian Gulf coast from Dubai to north of Ras Al Khaimah has alterations of sabkha, sand spits and islands with associated tidal lagoons and very occasional rocky outcrops.

3.2 SOILS

The significance of soil in a hydrogeological study is of two-fold interest; firstly, as the superficial cover through which any infiltration must take place; and secondly, as one of the two major limitations on irrigation-based agricultural development.

3.2.1 Occurrence: Any account of the soils of the northern part of the UAE must depend heavily upon the pioneering work carried out during 1966-67 by a team from the University of Durham (Bowen-Jones *et al*, 1967). Since the main agricultural soil resources in the area are associated with the western portions of the gravel plains their work tended to be concentrated in such districts.

In general they found:

"that there is no simple correlation between topography, vegetation and soil types, and the range of soils found is not only much greater than might be expected but includes variants of considerable importance to practical farming, e.g.:

- almost pure gravels some of which contain a very small but critical quantity of fine silts sufficient to impede drainage
- gravels with gypsum, gravels with high carbonate content, and gravels overlying silt loams
- heavy silts with no salinity, silts with coarser constituents and relatively high salinity
- sand with fine gravels, sand with coarse gravels and relatively high salinity and loam sands sometimes with high carbonate content.

Superficial examination reveals nothing of this variety ... the best soil in the south is marked by a bare surface of fine gravels which elsewhere would lead on to expect high gypsum content. These variations moreover occur over very short distances". (Bowen-Jones et al, 1967, p.14)

Given that the slopes within the gravel plains are exceedingly shallow, the vegetation rather sparse, and the rainfall much too little and sporadic for soil development, then it is clear that parent material becomes the dominant factor influencing soil formation. The soils are generally immature and three major soil types have been recognised by the Durham team and divided into series on the basis of texture and carbonate content as follows:

Carbonate content	0-25%	25-50%		50-100%
	Light	Heavy	Light	Light
SIEROZEM	C_2	C_3	C_4	C_6
NON-SALINE ALKALI	NS_2	NS_3	NS_4	-
SALINE ALKALI	-	SA_3	-	SA_6
When gravel occurs within 0·5 m of the surface the suffix (g) is used.				

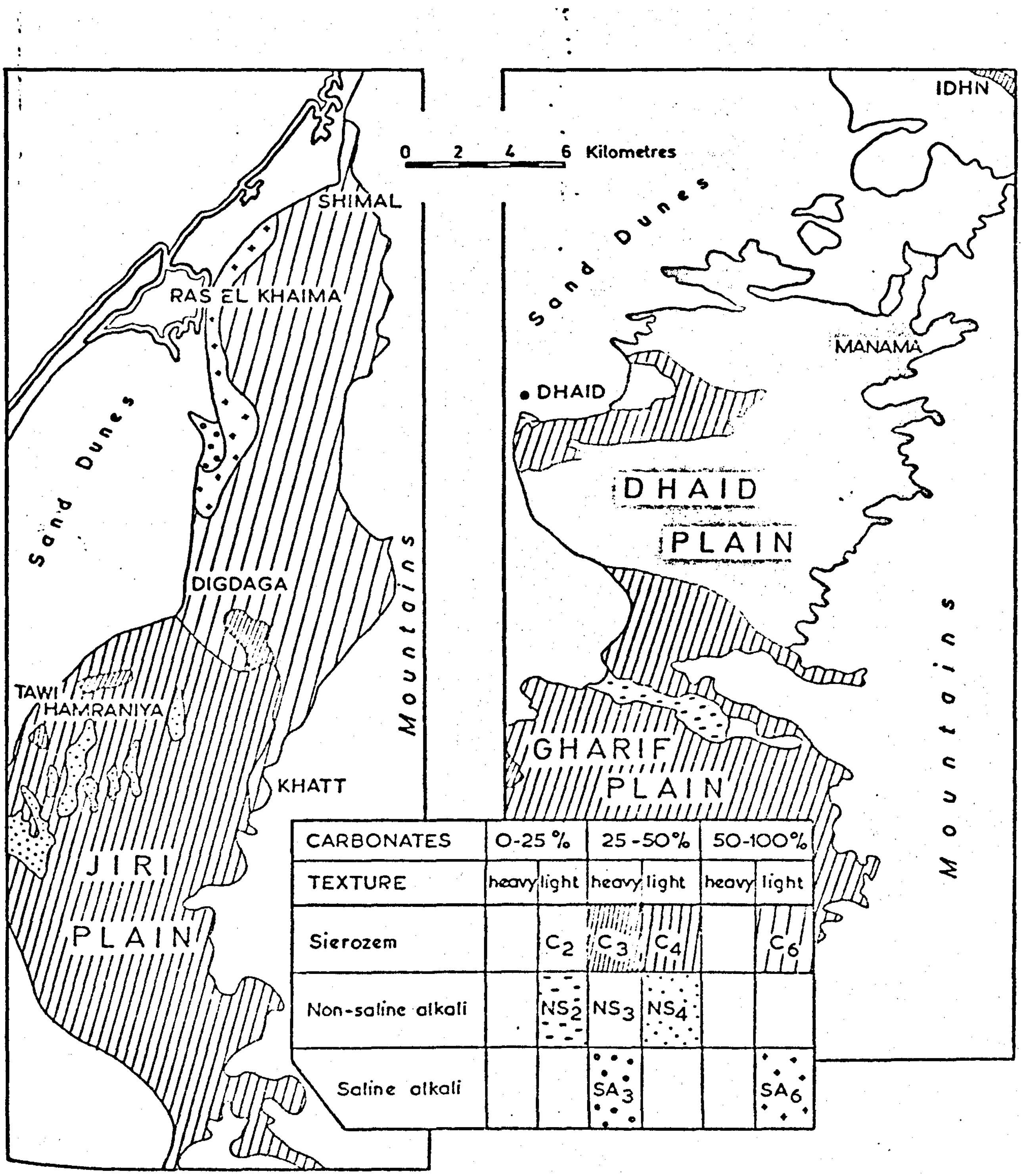


Fig. 3.2 Distribution of major soil types over gravel plain units

A generalised distribution of the major soil types over the gravel plains is given in Fig. 3.2 along with the location and classification of the soil conditions at the sites sampled by the Durham team.

Soil development outside the limits of the gravel plain are restricted to small areas of cultivation within the mountain range such as at Masafi and Idhn (where the soils are characterised by their extreme stoniness) and minor basins within the sand dune unit where C_4 soils with a silty loam texture overlie sand and at about 0·2 m below surface.

The major characteristics of the soil cover in the study area include:

(1) lack of well defined horizons other than depositional layers;

(2) platey structure underlain by subangular blocky structure;

(3) low organic matter content;

(4) presence of carbonates and/or gypsum;

(5) uniformly sandy texture;

(6) good drainage.

The northern part of the gravel plain exhibits a complexity of soils not found elsewhere. Soils of the C_6 series are associated with gravel outwash fan material extending from near Khatt northwards via Digdaga, to the east of Ras Al Khaimah and as far north as Shimal, beyond which the coastal fringe abutts directly against the mountain front. In the Jiri Plain to the south of Digdaga and west of Khatt, soils of the capital C_4 series predominate with tongues of non-saline alkali soils (NS_4) aligned roughly north-south. Near the western edges of the Jiri Plain may be found isolated patches of C_3 soil, and these high quality soils are responsible for the agricultural development that has taken place in the belt from Tawi Hamraniyah to Digdaga. Further north near Ras Al Khaimah, saline-alkali soils (SA_3, SA_6) occur adjacent to the former lagoon and surrounding districts, and agriculture is not possible.

The sand dunes extend eastwards to reach the mountain range in the vicinity of Idhn, and thus separate the northern and southern plains. The soils of the Dhaid Plain show some variety, though from Manama southwards they are dominantly of the C_2 series. The abundance of gravel in the soil and sub-soil provides one limitation on agricultural development, though it normally provides a highly permeable media for infiltration of rain water. A tongue of light textured C_4 series soil extends from Dhaid, where there is a localised occurrence of non-saline alkali soil (NS_2) due to the restriction of infiltration caused by a 'caliche' horizon at shallow depth.

Similar but larger occurrences of NS_2 and NS_4 soils are found in Gharif Plain to the south, but the predominant soil is of the light textured C_3 series ranging from gravelly in the east to sandy in the west. The isolated C_4 soil series development at Tawi Mileiha is probably due to the accumulation of silty material at the edge of the sand dune front.

3.2.2 Infiltration potential: Occasional ad hoc field observations were reported by Halcrows (1969, p.23) on the depth of saturated dune sand after specific periods of rainfall. In one case a heavy rainstorm of 11 mm (about one tenth of the long term mean annual rainfall) saturated the sand to a depth of only 40 mm; in another there was a depth of saturation of 45 mm resulting from a rainfall of 8 mm.

More scientific experiments to determine infiltration potential were undertaken by the Durham team using infiltrometers and by staff of the Agricultural Department to determine losses in irrigation canals.

Infiltrometers: The Durham team used stainless steel cylinders inserted vertically into about one foot of soil cover. The standard procedure used was to flood the cylinder to a uniform depth of about 10 mm and note the time taken for this quantity of water to infiltrate over successive periods up to 45 minutes duration. The method is subject to the usual constraints affecting the use of infiltrometers, though none was apparently taken to

TABLE 3.1 Canal Seepage Losses.

Location: Digdaga Agricultural Trials Station
Date: 2nd and 4th June 1966
Channel: Unlined irrigation ditch, not used 48 hours prior to tests
Length: 121.9 m

Duration of flow after starting pump hrs.min	Mean Wetted Perimeter m	Mean Wetted Area m^2	Flow		Losses		
			* Qu/s m^3/hr	Qd/s m^3/hr	m^3/hr	cm/hr	cms/sec x 10^{-3}
1.15			29.06	21.00	8.06	10.8	3.00
2.15			26.51	20.59	5.92	8.0	2.22
2.45	0.61	74.4	27.32	22.02	5.30	7.1	1.97
3.20			24.47	19.88	4.59	6.2	1.72

* Note: Difficulty was experienced in maintaining constant rate of flow during tests

Location: Kalba Agricultural Trials Station
Date: 10th August 1966
Channel: Unlined irrigation ditches in use for several hours before test

Length of reach	Mean Wetted Perimeter m	Mean Wetted Area m^2	Flow		Losses		
			Qu/s m^3/hr	Qd/s m^3/hr	m^3/hr	cm/hr	cms/sec x 10^{-3}
121.9	0.34	42.7	7.24	5.30	1.94	4.5	1.25
121.9	0.34	42.7	7.95	5.91	2.04	4.8	1.33
76.2	0.38	28.9	9.58	8.26	1.32	4.6	1.27
76.2	0.38	28.9	9.68	8.26	1.42	4.9	1.36

Location: Mileiha Irrigation Project wellfield
Date: 25th May 1967
Channel: Unlined ditch from borehole test vee notch tank. Flowing for 36 hours before test

Length of reach m	Mean Wetted Perimeter m	Mean Wetted Area m^2	Flow		Losses		
			Qu/s m^3/hr	Qd/s m^3/hr	m^3/hr	cm/hr	cms/sec x 10^{-3}
60.96	1.52	92.66	89.05	71.24	17.81	19.2	5.33
60.96	1.35	82.30	71.24	47.95	23.29	28.3	7.86
60.96	1.76	107.29	47.95	37.68	10.27	9.6	2.67
60.96	1.73	105.46	37.68	28.09	9.59	9.1	2.53
91.44	0.77	106.07	28.09	Nil	28.09	6.4	7.36

(Data from S.W.H. Report, 1969).

limit lateral spreading and minimise disturbance during insertion into the soil.

Over the areas investigated there was a range of total infiltration values from 10 mm to 167 mm and by the end of the 45 minute standard test period most infiltration curves had levelled off to a constant rate of infiltration. Since the major factor controlling infiltration is the volume and distribution of void space in the soil and sub soil, it was not surprising that the higher infiltration rates were associated with low silt and clay contents in the surface layers. Most of C_4 soils were able to absorb 100 mm or more during the test period, and any such soils with lower values were considered to be affected by the presence of surface silts. The C_3 series had a lower intake for the most part with occasional anomalous values attributed to surface cracking in the soil. One might not have expected the C_2 soils with their low proportion of fine grained material to provide the lowest infiltration rates in the range of 30 to 50 mm over the standard test period. A combination of silty surface and low carbonate content seem to have been responsible.

Canal losses: Tests to determine seepage losses from unlined canals were carried out in 1966 and 1967 at two locations within the study area. At the Agriculture Trials Station at Digdaga an existing irrigation channel which had not been in use for two days previously was selectively flooded for progressively longer periods of time with results as given in Table 3.1 (a). In the case of the test at the wellfield associated with the Mileiha irrigation project, the channel used was a newly dug ditch carrying water from a test borehole. Water had been allowed to flow into the ditch for some hours prior to the test so that fully saturated soil conditions can be safely assumed. The results are reported in Table 3.1 (b), and diagrammatically represented in Fig. 3.3 along with those from the Digdaga test. In both test situations the rate of infiltration appeared

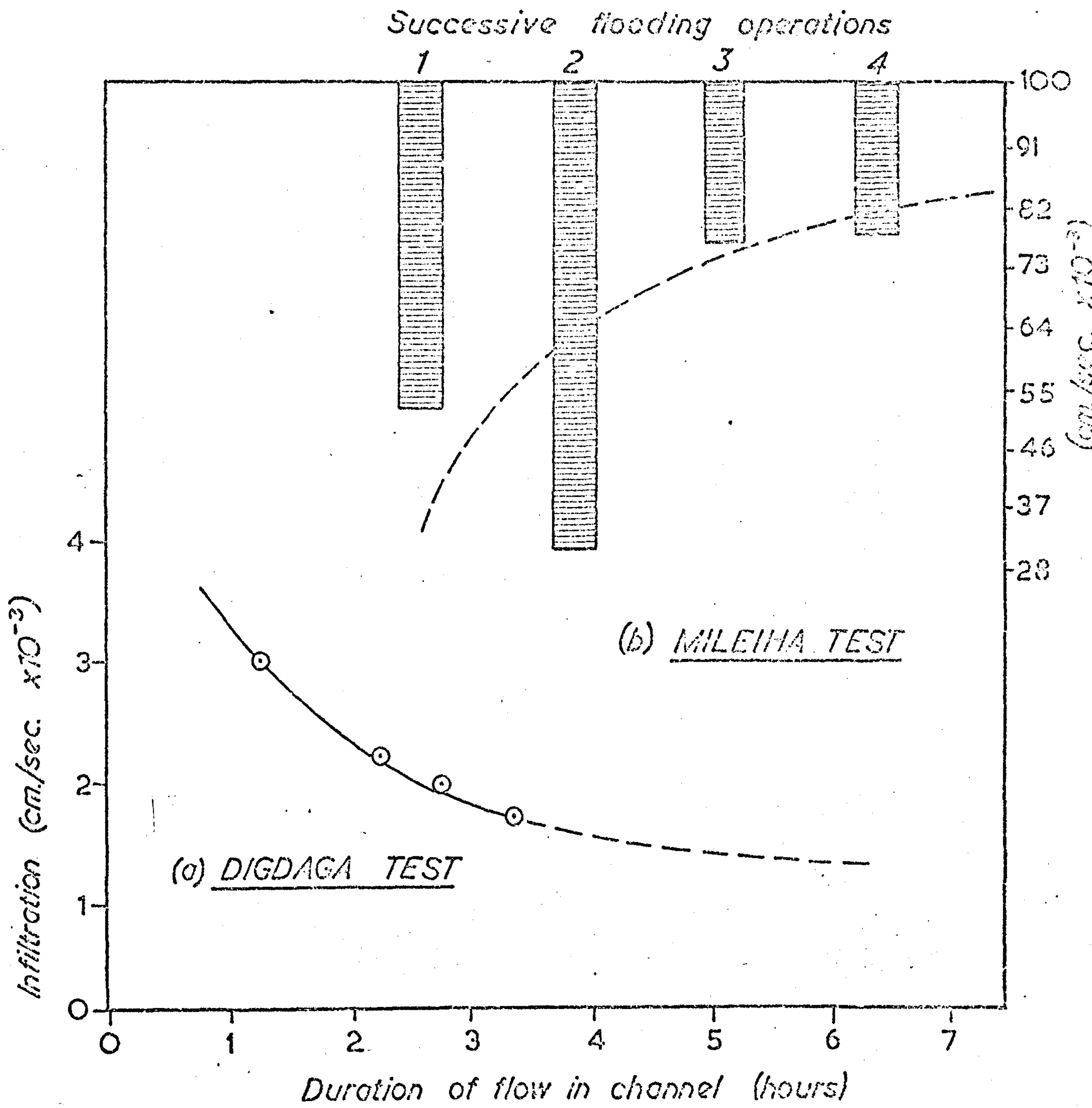


Fig. 3.3 Diagrammatic representation of infiltrometer results

to gradually decrease after heavy initial losses; the Digdaga results are easier to interpret and by graphical extrapolation in Fig.3.3 the approximate equilibrium infiltration rate would have been about $1{\cdot}5 \times 10^{-3}$ cm/sec compared with a more doubtful value of about 2×10^{-3} cm/sec at Mileiha.

The observed seepage rates depended more on local than regional soil characteristics so that in their application to the replenishment potential of existing aquifers considerable caution must be exercised.

4. HYDROMETEOROLOGY

4. HYDROMETEOROLOGY

4.1 Introductory Remarks

Meteorological records for the area under study are of relatively short duration and somewhat incomplete by comparison with British or European standards. Nevertheless, the availability of a variety of data over a ten year period provides a valuable basis for water resources studies so long as the limitations of such records are understood and accepted. Meteorological observations commenced in 1934 with rainfall measurement at the Sharjah air-base, though this remained the only station maintaining regular observations in the whole of what is now the UAE until the early 1960's. Two rain gauges were then installed in Dubai and a further sixteen were set up by the Water Resources Survey (WRS) in the Northern Emirates during the period 1965 to 1968. Of these, four namely Digdaga, Falaj al Mu'alla, Mileiha and Masafi lie within the study area. The Burairat station was subsequently installed by the Ministry of Agriculture and Fisheries in 1972. Figure 4.1 shows the locations of all the relevant stations.

Data collected from the stations were collated on the basis of a Hydrological or Water Year, commencing on 1st October and ending on 30th September, based on the long-term, mean-monthly rainfall distribution at Sharjah. Sir William Halcrow and Partners (SWH), the consultants initially responsible for the Survey, published the basic hydrological data in three yearbooks for 1965/66, 1966/67 and 1967/68. The work was subsequently taken over by the Trucial States Council (TSC) who published the yearbook for 1968/69 in 1970 since when it has been the responsibility of the Rural Water Section of the UAE Ministry of Agriculture and Fisheries (MAF) who in 1973 produced a Statistical Yearbook summarising in Arabic the data for the period 1969/70 to 1972/73. The data for water years 1973/74 onwards are not yet published but for the most part are compiled and available for study in the Meteorological

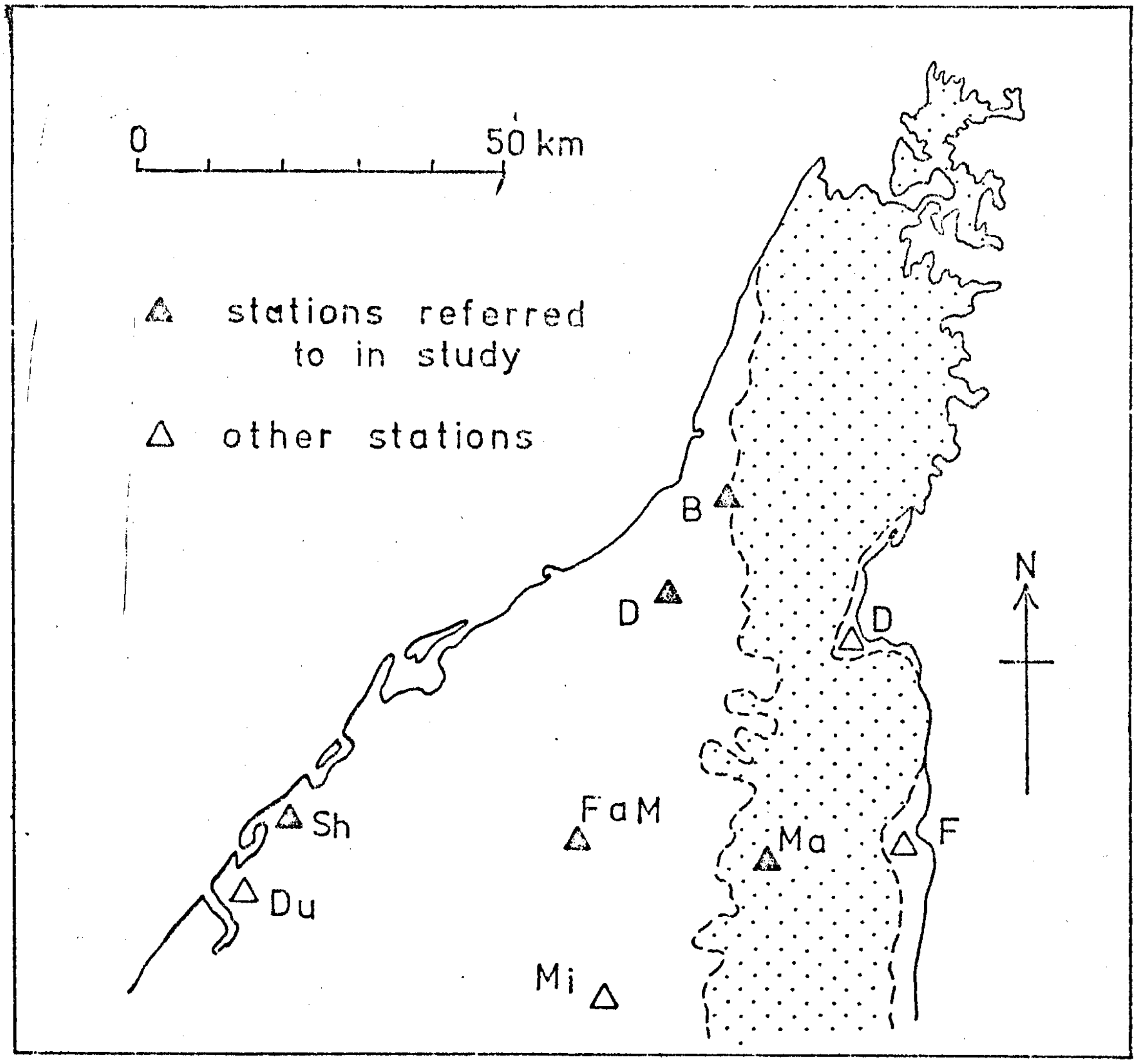


Fig. 4.1 Distribution of hydrometeorological stations in northern UAE

Sections of the MAF at Dubai and Digdaga. From a water resources viewpoint, the most important meteorological parameters are rainfall and evaporation, but other parameters relevant to such studies are available as indicated in Figure 4.1. For this reason, temperature, wind, relative humidity and radiation, all receive some consideration in the following pages in addition to rainfall and pan evaporation.

No guarantees are available regarding the accuracy of the data either as measured or as reported. In some cases station sites have been moved short distances since first installed, while changes in staff have been commonplace over the measurement period. More fundamental and disconcerting is the disparity in records for the same time period at the same site under the responsibility of the same authority. For example, the tabulation below shows discrepancies in annual rainfall measurements reported in millimetres for Falaj al Mu'alla over a four year period:-

Hydrological Year	MAF (1973)	MAF (ARS)	FAO (1973)
1969/70	68·52	1·02*	81·7
1970/71	18·0	28·0	53·1
1971/72	189·7	139·7	139·7
1972/73	29·7	29·7	-

* incomplete record. - no information

MAF 1973: Statistical Yearbook 1973 (in Arabic).

MAF (ARS): Records available at Digdaga Agricultural Research Station.

FAO: UN (FAO) Report, 1973.

The anomalies are undoubtedly human errors that have arisen subsequent to the measurement reading either due to incorrect copying, or copying of incomplete data or simply due to mistyping that has passed without notice into publications. For example, one is tempted for 1971/72 to view 1<u>8</u>9·7 as a mistyping of 1<u>3</u>9·7, but it is impossible to reconcile the other differences except to give preference to the complete record over the incomplete record. The previous example is not unusual, and similar anomalies may be found in the monthly and annual records of most stations and occur in all years subsequent to 1968/69 including the most recent year's record.

4.2 TEMPERATURE

Air temperature data are recorded twice daily for stations within the study area and are available for mean minima, mean maxima and means on a monthly basis. These have been collected over the study period for the above mentioned stations (Table 4.1) and the data are graphically presented in Figure 4.2, which shows the hottest and coldest months as well as the wide range in temperature. Of course, the actual air temperatures will be higher or lower than the mean maxima and minima, and even higher out of the shade. For instance, at Burairat station for the most recent hydrological year, 1975-76, the absolute minimum was 12° C in January compared with the monthly mean minimum of 14·9° C, and the absolute maximum was 43·3° C in May compared with the monthly mean maximum of 38·0° C. The highest and lowest temperatures recorded within the area during the study period were respectively, 47·8°C at Mu'alla and -1·1°C at Digdaga.

In general, the coldest months are January and February with June, July or August providing the hottest months. It is interesting to note that the monthly temperature range at any one station appears to remain relatively uniform regardless of season, though there is some variation from one location to another. It may be seen that the temperature range is greater as one proceeds away from the coast, with correspondingly lower minimum and higher maximum temperatures.

The major cause of the range in temperature on a daily basis as well as from one locality to another is the effect of insulation as represented by

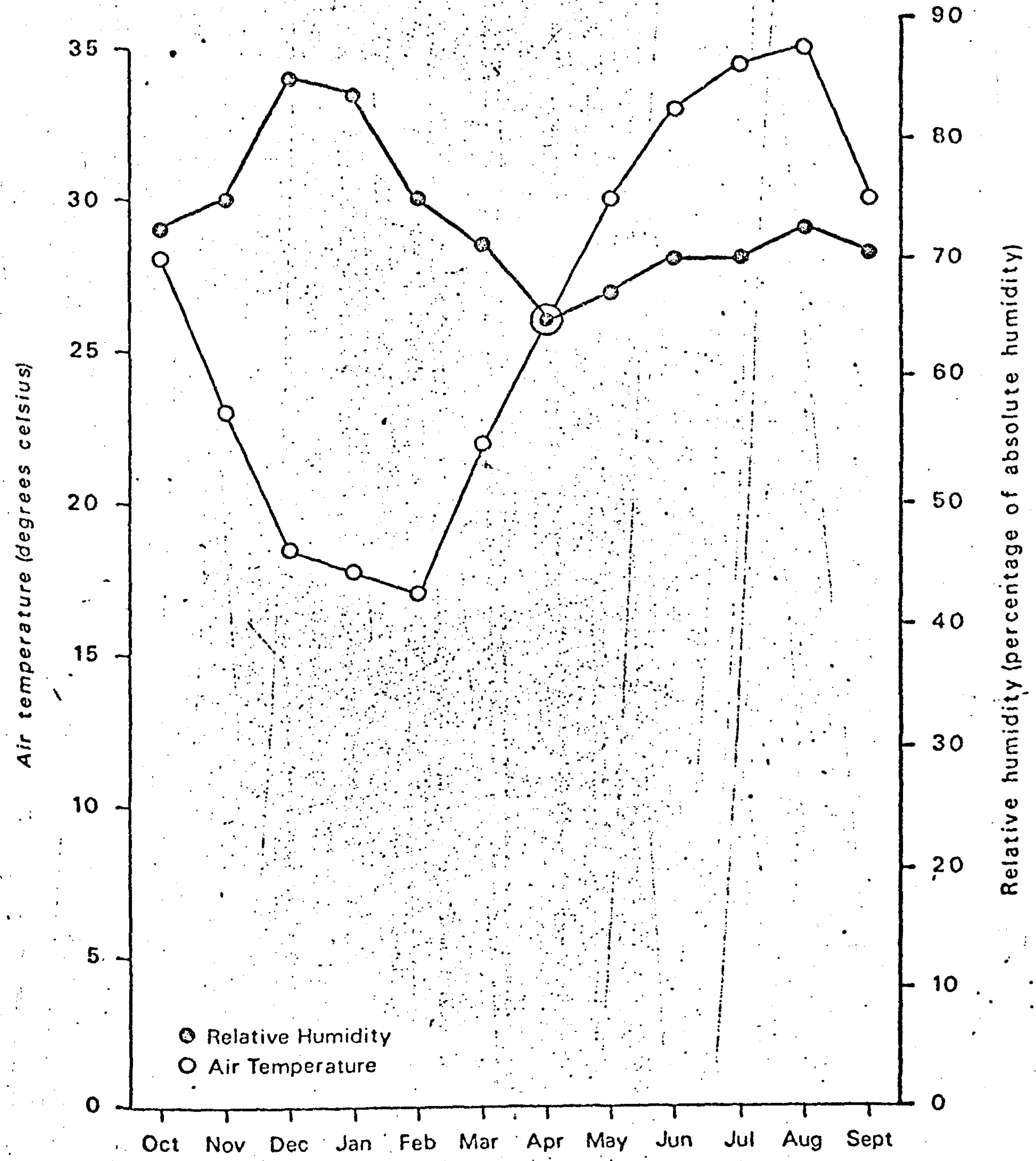


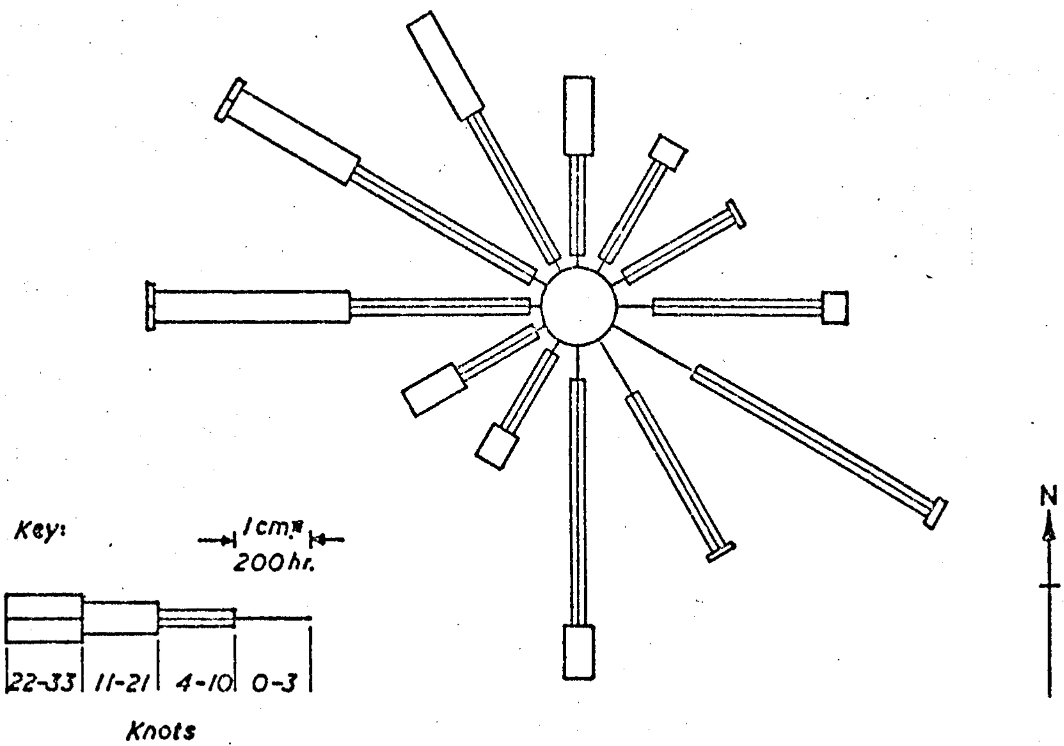
Fig. 4.2 Mean monthly air temperature and relative humidity for Falaj al Mu'alla

intensity of solar radiation. There is little or no cloud cover for much of the year so that incoming radiation is virtually unaffected. In consequence the land surface heats up rapidly during the daytime, but the absence of the cloud cover at night allows the outgoing heat radiation to be lost to the atmosphere with a resultant rapid fall in night-time air temperatures to below zero in some cases during the colder months, as at Digdaga in December, 1974. Since radiation is also affected by the albedo or reflective ability of the surface materials (natural and artificial) one would expect, in theory, to find a different diurnal range in the dark-coloured mountain areas in comparison with the light-coloured desert and gravel plain areas. This is not borne out by the data.

4.3 WIND

A tri-cup anemometer is usually located at heights from 25 cm to 1 m from the ground within the hydrometeorological station compounds to measure daily totals of wind movement, but not direction. The results (expressed in km/day) are reported as maximum, minimum and mean values, though at some sites the readings may be affected by nearby trees and/or buildings. Monthly mean wind movements is given in Table 4.2 for selected stations over the study period, and mean monthly values are illustrated in composite Figure 4.3 for some of the stations in question. The coastal station at Sharjah experienced the highest wind movement followed in sequence by Mileiha, Falaj al Mu'alla. Their location and degree of shelter may explain the variations.

The highest average wind movement appears to occur during the summer months, with lower movements occurring during the cooler period, though completely calm periods in excess of one day are rare. This high summer activity may be explained by reference to the previously considered solar radiation and temperature parameters which are conducive to the formation of strong convection cells with rapid air movement at their base. The convection



WIND SPEED & DIRECTION AT SHARJAH

Total for 1966

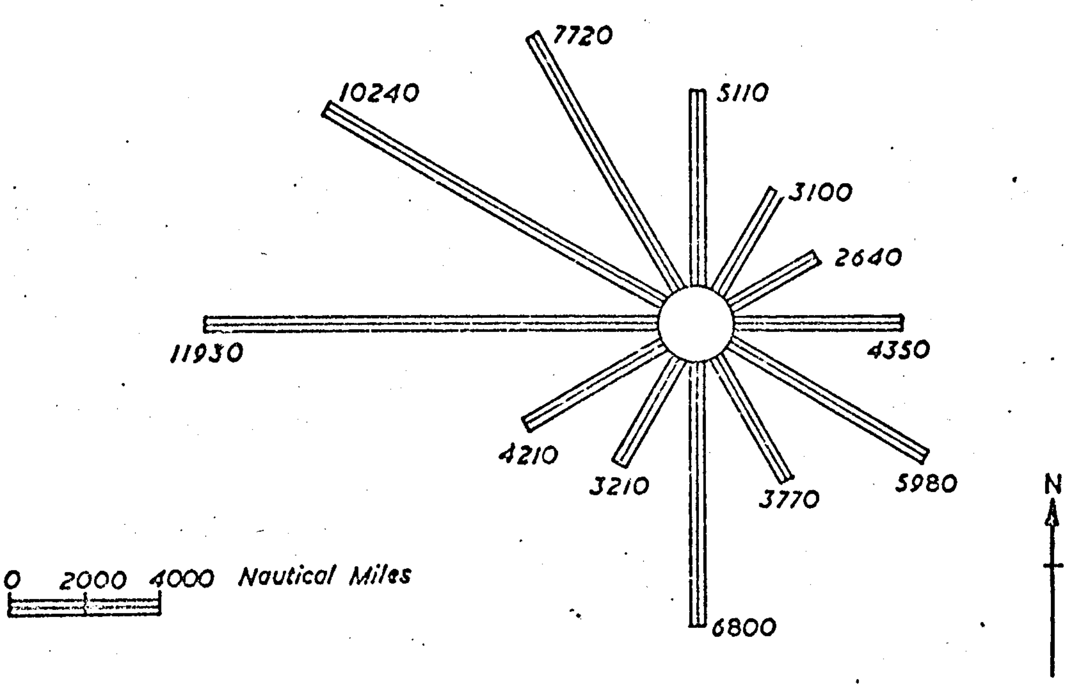


Fig. 4.3 Wind speed and direction at Sharjah (after SWH).

	Sharjah		Digdaga		Falaj Al Mu'alla		Mileiha	
Month	Mean Min.	Mean Max.	Mean Min.	Mean Man.	Mean Min	Mean Max.	Mean Min.	Mean Max.
Oct.	22.3	34.5	18.6	37.5	19.4	38.4	18.8	38.2
Nov.	17.2	30.3	17.5	32.2	16.3	32.4	16.5	31.9
Dec.	13.2	25.3	9.6	25.3	10.3	25.4	10.2	24.9
Jan.	12.1	23.7	7.1	25.7	10.2	25.0	10.9	24.0
Feb.	14.3	23.3	10.0	25.7	11.9	25.9	11.6	22.2
Mar.	16.6	27.2	14.0	31.4	14.0	30.3	13.5	30.8
Apr.	18.6	30.1	15.3	33.0	16.1	33.9	16.1	34.2
May	21.5	33.4	19.5	39.3	20.4	39.5	20.1	39.0
June	23.8	34.9	22.1	41.6	28.1	42.6	22.4	42.6
July	27.4	38.6	26.6	43.0	26.8	44.2	26.2	44.2
Aug.	27.2	37.6	27.3	42.6	25.8	43.6	26.1	43.8
Sep.	25.3	36.0	23.2	40.7	23.1	42.0	23.2	42.1

Table 4.1 Temperature (^{o}C) at selected stations.
(from SWH, 1969)

Wind Speed Knots	Total Number of Hours from (degree true)											
	350 -010	020 -040	050 -070	080 -100	110 -130	140 -160	170 -190	200 -220	230 -250	260 -280	290 -310	320 -340
0-3	31	36	40	93	247	165	90	38	26	23	37	30
4-10	255	288	325	444	718	460	628	241	237	478	546	438
11-21	204	63	18	66	29	14	137	89	156	518	364	287
22-23	-	-	-	-	-	-	1	1	-	9	19	-
Wind Movement Nautical Miles	5111	3096	2643	4350	5984	3774	6795	3214	4207	11927	10242	7718

Table 4.2 Wind Direction and Velocity at Sharjah (1966)

Table 4.3: Relative Humidity Data (%) for selected stations for hydrological year 1974-75.

Month	SHARJAH			BURAIRAT		
	Min	Mean	Max	Min	Mean	Max
Oct	32	65	94	-	-	-
Nov	28	70	100	-	-	-
Dec	42	71	92	22	59	90
Jan	43	75	98	30	63	100
Feb	40	77	100	28	60	90
Mar	13	63	100	12	41	78
Apr	25	62	92	14	42	84
May	22	53	90	8	34	85
Jun	24	66	98	26	58	88
Jul	42	68	93	30	57	85
Aug	25	67	93	32	58	88
Sept	26	62	97	25	55	96

Table 4.4: Mean monthly evaporation from Class "A" Pan (mm) (1968-72).

Distance from coast (km)	Sharjah (1)	Digdaga (12)	Falaj al Mu'alla (38)	Mileiha (53)
October	263.3	253.3	301.5	315.4
November	190.5	193.5	212.5	208.5
December	150.3	151.9	153.0	185.3
January	147.9	124.8	154.9	177.7
February	142.7	128.8	123.9	149.8
March	203.0	195.1	237.1	288.2
April	234.0	273.0	326.2	305.5
May	310.8	344.0	384.4	426.3
June	374.2	362.7	465.7	528.7
July	345.7	378.2	411.4	499.0
August	353.7	393.7	434.7	577.3
September	267.0	274.0	372.8	388.5
TOTAL	2983.1	3073.2	3577.8	4050.2

updraughts thus encourage an increase of wind movement at near surface levels. A complementary temperature inversion effect at night may itself produce strong winds particularly in localities adjacent to the mountain areas.

The only information available on wind direction is that provided from the anemometer installed at a height of 10 metres by the R.A.F. at Sharjah in 1965. In their report of 1969, the staff of Sir William Halcrow and Partners studied the records for 1966 in great detail and it is considered sufficient for this aspect to reproduce their main findings in Figure 4.3. Westerly and north-westerly winds appeared to predominate in 1966, with the higher wind movements confined to these directions; a significantly southern wind was a feature of the hotter months, while easterly and south-easterly winds seem prevalent in the early part of the cooler months. It must be remembered that these comments are in relation to the exposed coastal site at Sharjah and may not be representative of areas inland, for which no such data are available.

4.4 RELATIVE HUMIDITY

Measurements of relative humidity are made twice daily using wet and dry bulb thermometers at all the hydrometeorological stations within the study area, and are available as maximum, minimum and mean monthly values. Table 4.3 gives the mean monthly values for the relevant stations and they are graphically presented in Figure 4.2.

The relative humidity varies seasonally, and as with temperature frequently demonstrates an extreme range of values within the same time period. It is usually highest during the winter season and lowest during the early part of the summer season when the effect of the dry southerly winds is noticeable. Later in the summer months the humidity rises as a consequence of warm, moist air drawn from the west, and this rise, together with the increase in summer temperatures, creates conditions that are uncomfortably oppressive and sultry. Use of mean monthly values tends to ignore the extreme diurnal variations of relative humidity which can range from less than twenty percent at noon to something in excess of ninety percent at night, with occasional formation of dew.

4.5 PAN EVAPORATION

Daily measurements of evaporation have been made at localities within the study area by use of standard U.S. Weather Bureau Class A pans, though there are frequent breaks in the continuity of the record. Table 4.4 gives the available monthly values for selected stations in the study area and the mean monthly and annual data are graphically presented in Figure 4.5.

As expected, the evaporation varies seasonally, and given the continuous open water surface at the pan, will depend on the combination of the meteorological parameters of temperature, solar radiation, wind movement and relative humidity that have been considered previously. The highest values for evaporation loss occur in the hotter summer season with lower values corresponding to the cooler winter months, regardless of location within the study area. The significance of location does, however, appear to be important so far as the quantity of evaporation loss is concerned. When the mean annual evaporation data are tabulated for the study area, then a pattern seems to be present, with evaporation increasing with distance from the west coast.

Table 4.4 presents mean monthly evaporation data from class 'A' pans for four stations in the study area arranged relative to elevation and distance from the Arabian Gulf. It may be seen that evaporation increases away from the coast at Sharjah to Mileiha at the mountain edge. Seasonal variation at all sites is clearlt demonstrated in the related Figure 4.5 with winter low values contrasting markedly with the summer maxima. The annual potential evapotranspiration can be roughly calculated by multiplying the evaporation values from class 'A' pans by a factor of 0·7 which gives a range for evapotranspiration from 2090 mm at Sharjah to 2840 mm at Mileiha. These values will vary with the type of vegetation and its stage of growth.

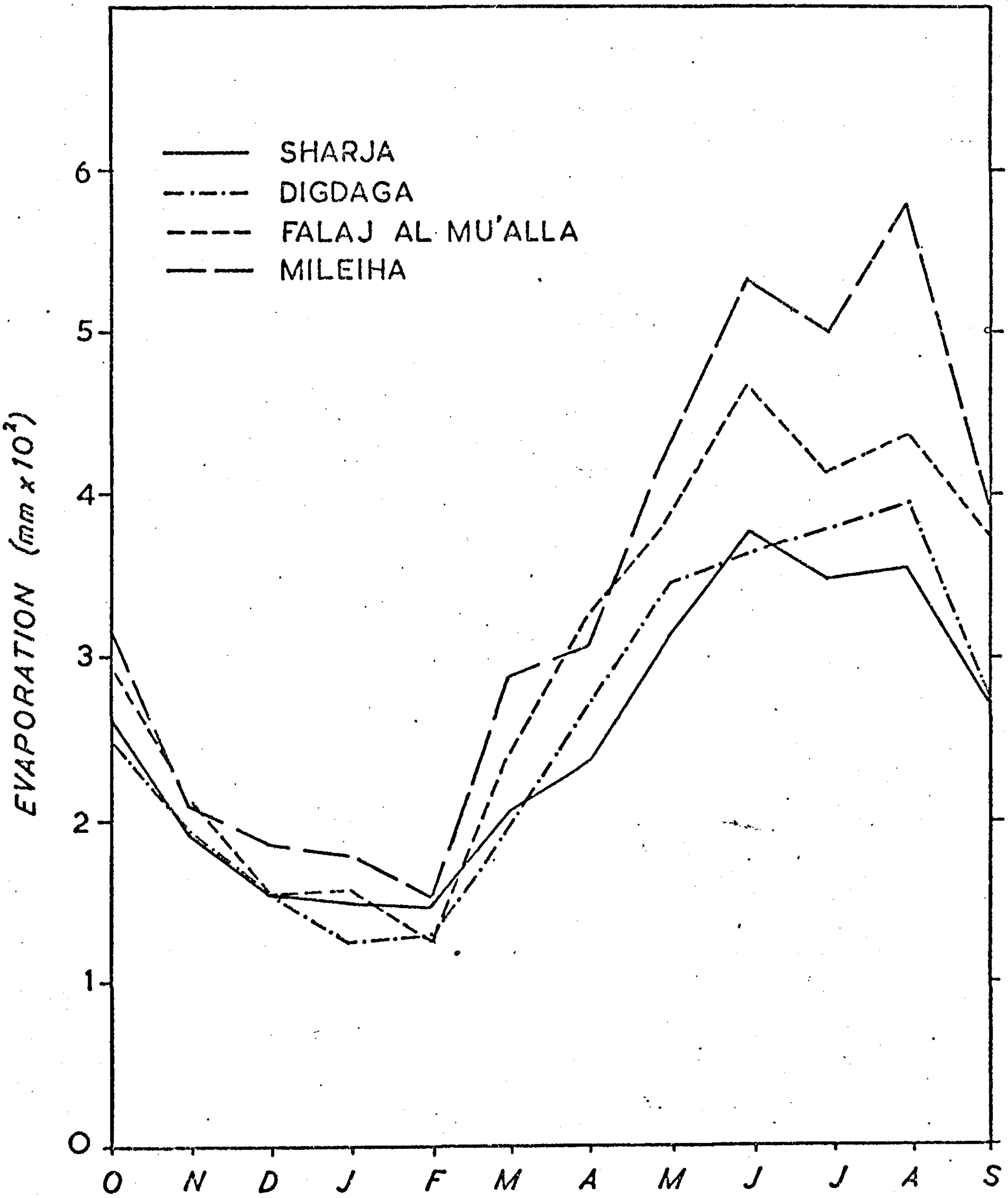
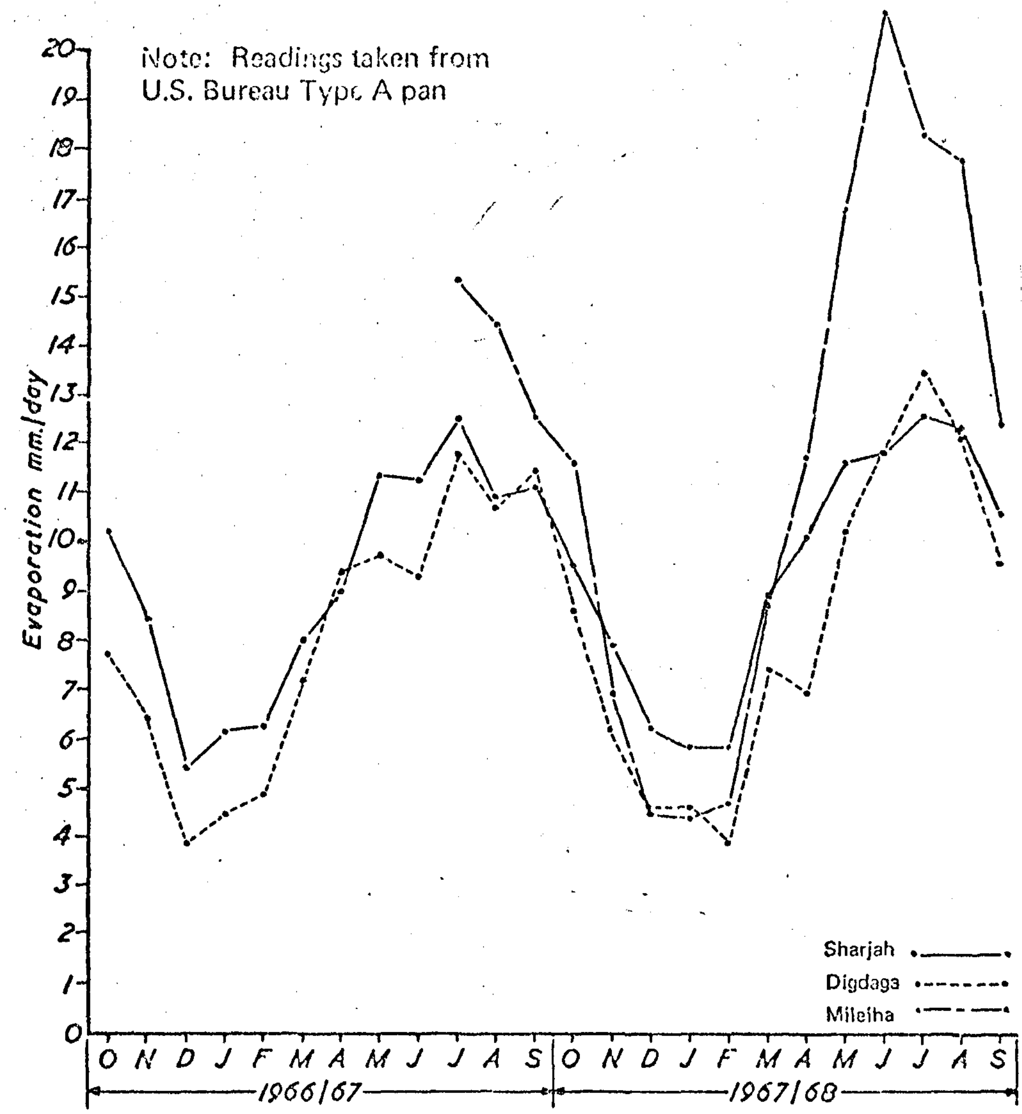
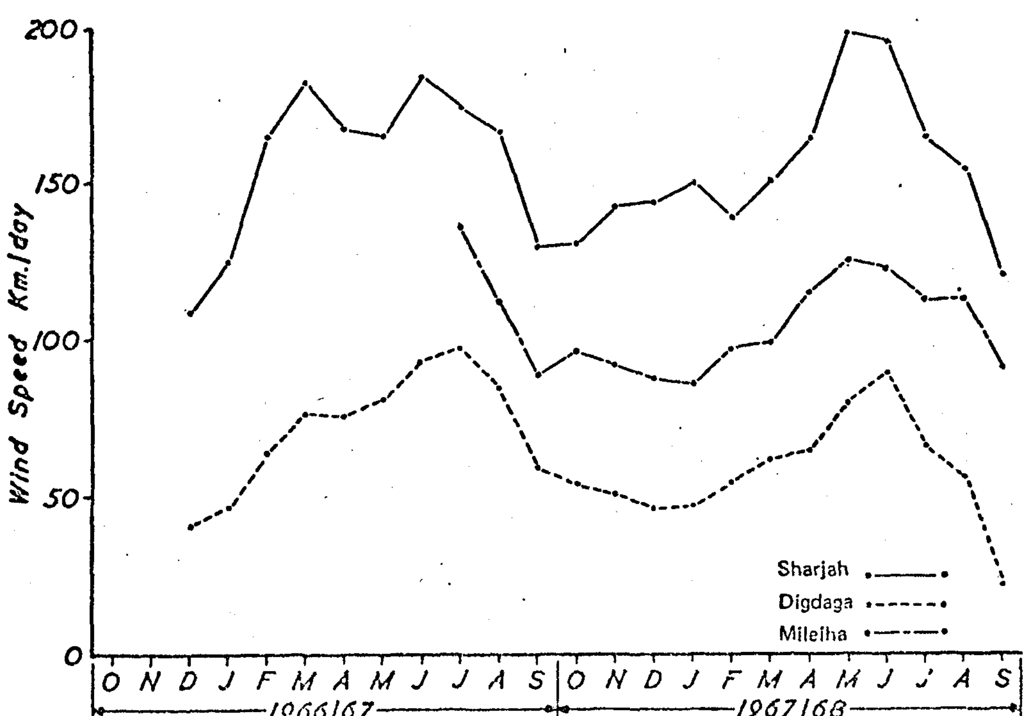


Fig. 4.5 Evaporation data for selected stations



MEAN MONTHLY EVAPORATION – OCT. 1966 – SEPT. 1968



MEAN MONTHLY WIND SPEED – OCT. 1966 – SEPT. 1968

4.6 RAINFALL

The prime characteristic of arid regions is a sparse rainfall that exhibits areas and temporal variation. In general one finds that the lower the mean annual rainfall, the greater is the annual variation and degree of unreliability. This very variability makes even more difficult the prediction of rainfall events in the UAE from the short duration of climatological data. Annual rainfall for the period October 1965 to September 1976 is presented in Table 4.5 for the stations in the northern UAE. The data for four selected stations in the study area for the same period is represented in Figure 4.6 (a) on a water year basis. While the annual variability is well shown there is sufficient similarity of response among the selected stations to justify the extrapolation of the long-duration record at Sharjah to other parts of the area.

Mean monthly rainfall at Sharjah and Digdaga is illustrated in Figure 4.6(b) where the long-term average record (1934-68) shows a frequency distribution of winter rainfall stretching between November and May. The short-term record for the individual hydrological year 1973-74 shows a more typical distribution and also emphasises the variability of the record. It is generally assumed that the majority of the rain that falls during the winter months is related to low pressure frontal systems which create an orographic effect as they cross the Oman mountain range and there give rise to rains of greater intensity and duration than on the plains and desert in the west. Such rain as falls during the summer months is derived from conventional storms which tend to produce heavy but short duration localised showers.

In concluding this chapter it is necessary to emphasise the uneven distribution of the meteorological stations and the doubtful validity of some of the existing data so that too much reliance is not placed upon information that may prove crucial to water resources studies.

TABLE 4.5 : Annual rainfall for selected stations from October 1965 to September 1976 (mm).

Masafi	72.3	67.3*	106.6	181.2	60.1	36.3	195.0	83.2	41.0	304.5	357.1
Masfut	103.0	84.0	109.1	130.4	64.1	26.1	224.6	4.3*	29.9	-	-
Dibba	50.6	20.8	88.9	166.0	44.6	29.4	199.1	93.7	11.9	-	-
Fujairah	99.1	1.6*	121.7	206.8	88.1	65.8	150.9	21.9	20.4	-	-
Kalba	NR	21.8	110.0	123.7	35.4	50.1	266.2	20.2	23.4	-	-
Manama	63.5	52.5	107.7	163.3	38.0	53.6	101.8	2.2	36.0	-	-
Falaj al Mu'alla	86.9	5.9*	79.9	124.5	81.7	53.1	139.7	29.7	18.6	134.6	210.7
Jebel Faiyah	13.8*	16.5*	130.1	216.4	-	22.8	91.9	63.4	60.0	-	-
Mileiha	NR	34.0*	120.0	135.6	93.8	22.8	179.6	65.4	8.6	134.6	275.9
Digdaga	61.0	17.5	66.6	118.6	27.1	106.7	182.8	54.3	12.3	57.4*	240.3*
Dubai	NR	23.1*	104.1	123.3	(88.0)	90.7	96.0	25.4	4.7	-	-
Sharjah	60.8	11.5	81.8	139.8	72.2	206.2	146.3	51.7	3.1	167.4	148.2*
Buraiyrat	NR	NR	NR	NR	NR	NR	NR	75.8	14.7	234.0	294.2

NR = not recorded * records incomplete - = no information

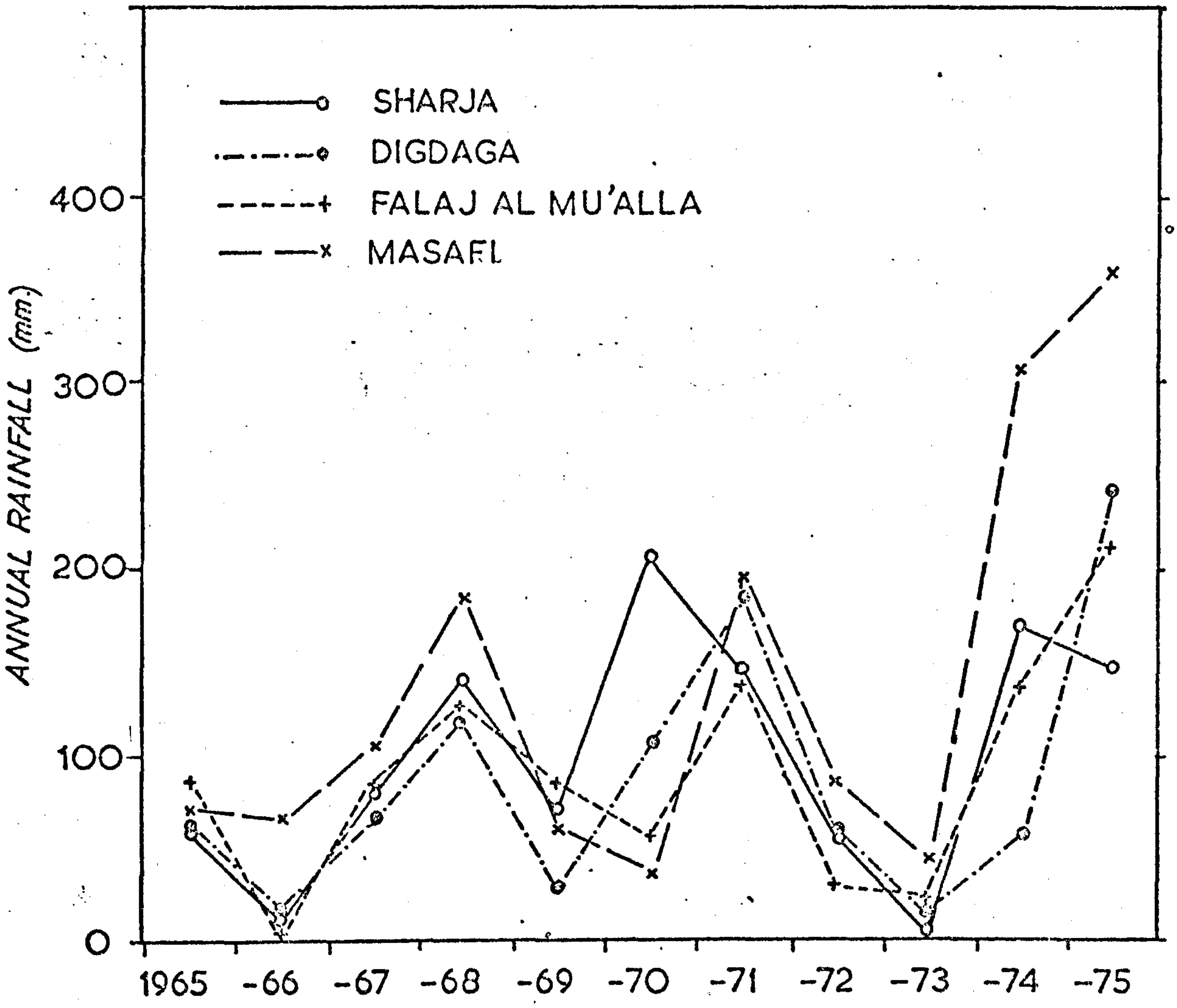


Fig. 4.6 Annual rainfall data from selected stations.

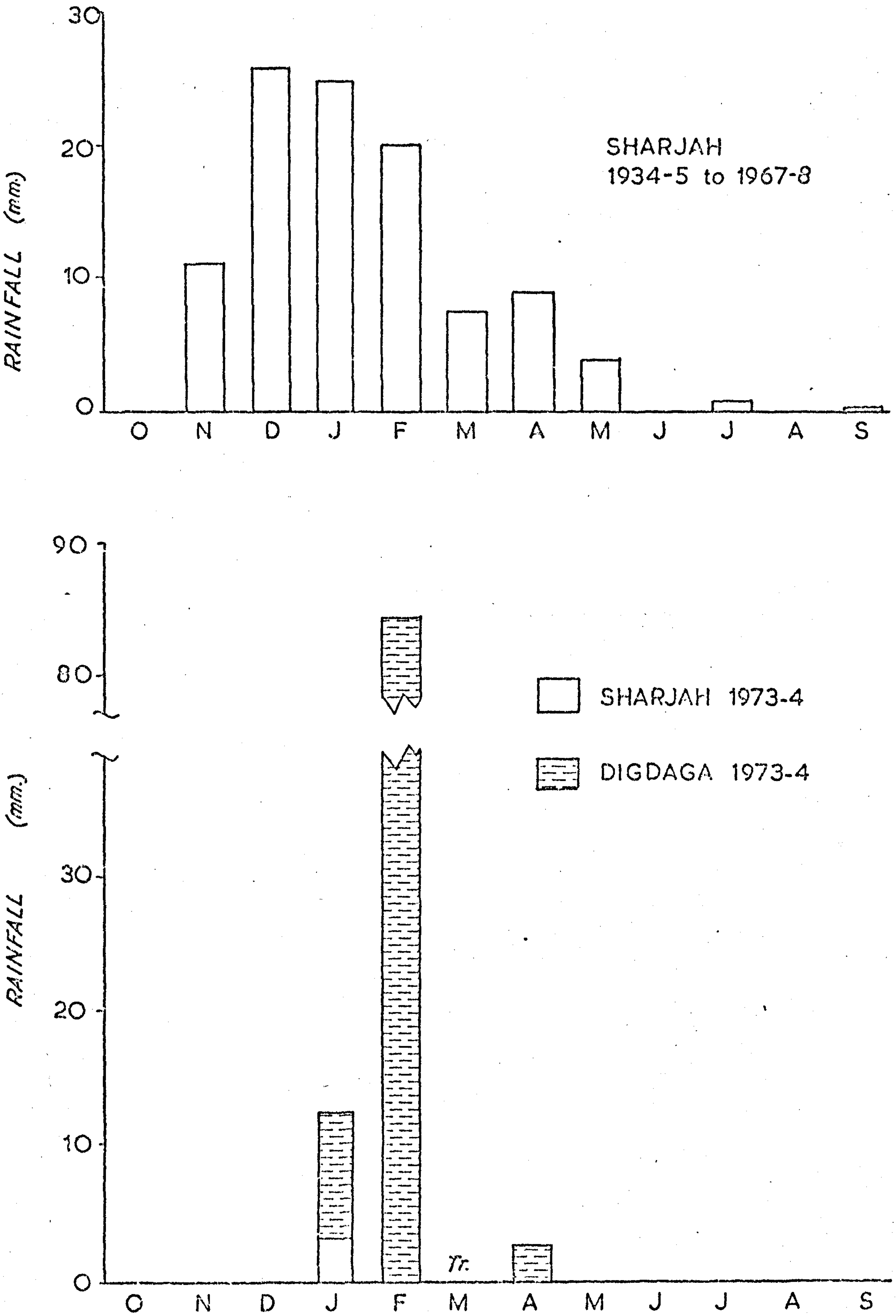


Fig. 4.6(b) Monthly rainfall data for selected stations

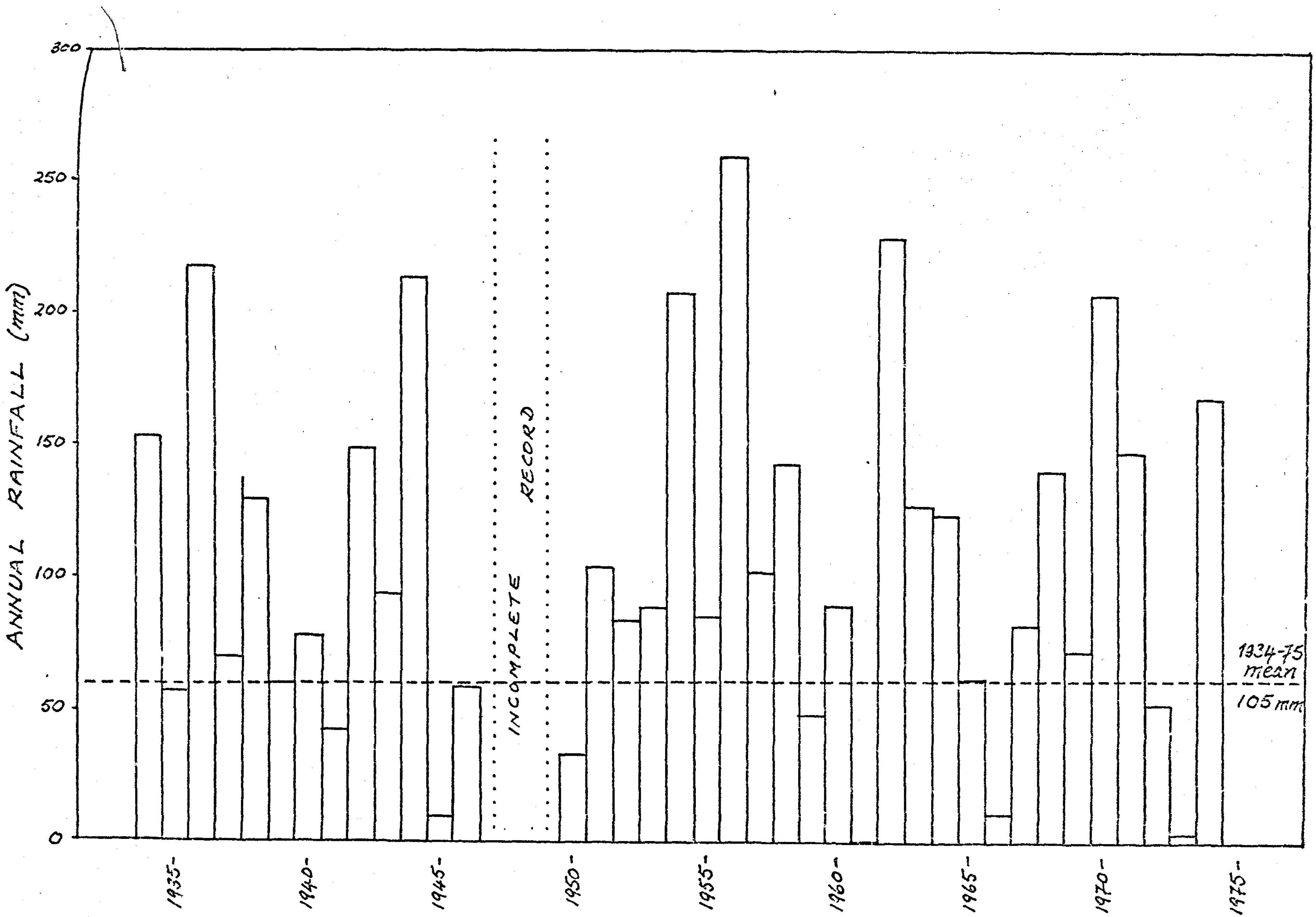


Fig. 4.7 Long term annual rainfall at Sharjah

5. SURFACE HYDROLOGY

5. SURFACE HYDROLOGY

5.1 CATCHMENTS AND DRAINAGE

In the Mountain unit the catchment areas are dominantly made up of steep slopes consisting either of bare rock or scree. In the mountainous areas the wadiis have cut deep 'V' shaped valleys into bare rock, while in the bottom of the valleys there are narrow gravel and conglomerate terraces into which channels have cut to expose coarse gravels and boulders. Vegetation and soil cover is negligible so that it is estimated that 85 percent or more of rainfalls of moderate to heavy intensities makes its way to the valley bottoms. Part of this surface runoff infiltrates into the wadi bed and/or terrace gravels which provide temporary ground-water storage. The remainder flows down the channel of the drainage network and either is steadily diminished by continuing infiltration, or alternatively if the rainfall should have been both excessive and heavy, the wadi flow will steadily gain discharge until it flows over the alluvial fans at the entrance to the gravel plains.

The mountain catchments that contribute to the gravel plains are shown in Enclosures 5.1, 5.2 and 5.3, with estimates of their respective areas tabulated in Table 5.1. It may be seen that while most of the contributary areas are relatively small, some like that of the Siji are large, while that of the Bih at approximately 440 km^2 is enormous in relation to those previously mentioned. None of the catchments carries any perennial surface flow, but in spite of this there are numerous well-defined wadis and contributory valleys so that the potential drainage network is extensive and well-developed. Their diagrammatic representation in Fig.5.1 emphasises that only few of the catchments combine sufficient size with contributions from highest parts of the mountain system to enable a build-up of significant discharges. Such flood discharges that reach the mouths of the catchments to provide

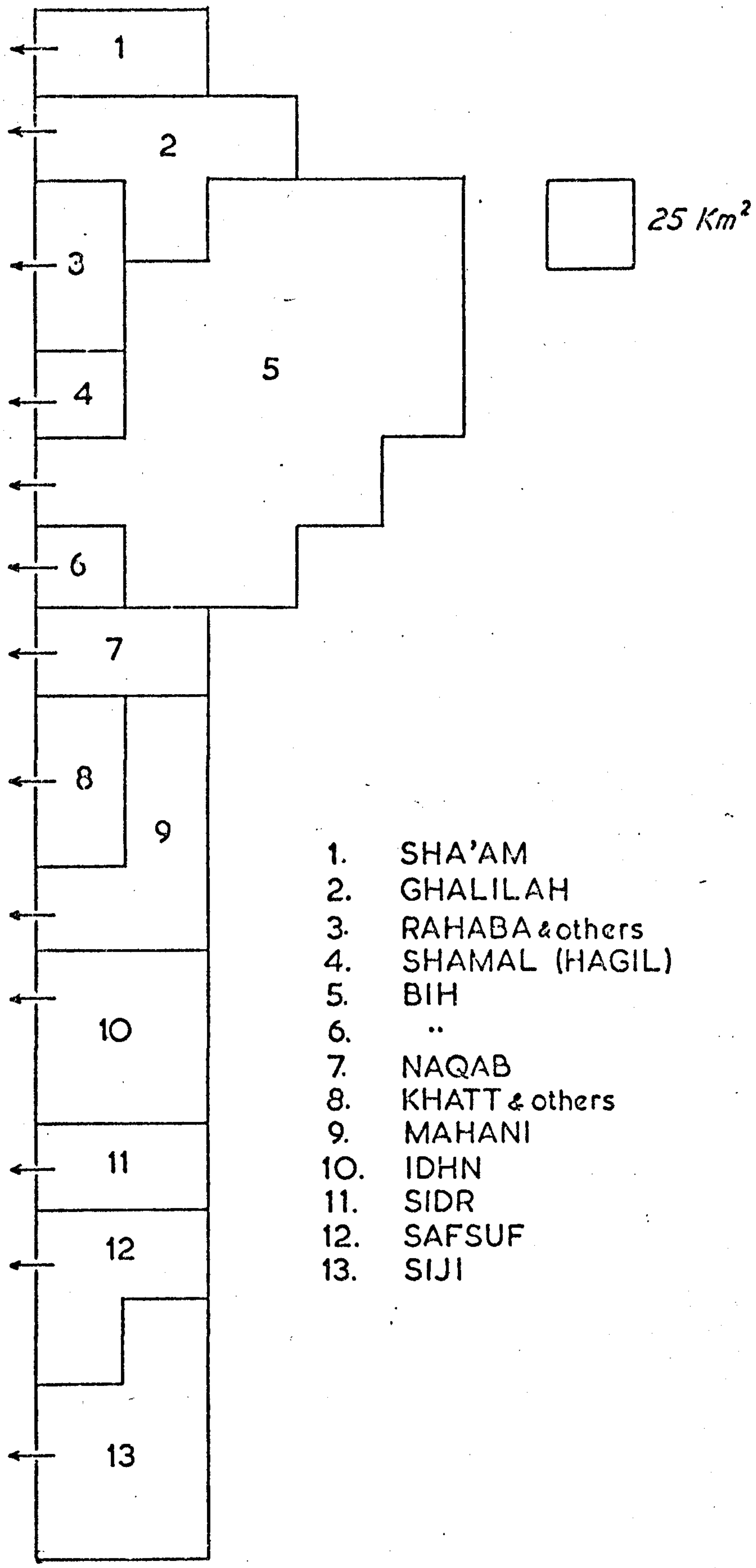


Fig. 5.1 Diagrammatic representation of westerly draining catchments.

Table 5.1: Approximate size of mountain catchments.

	Catchment	Size (km^2)
1	Sha'am	50
2	Ghalilah	98
3	Rahaba, etc.	48
4	Shamal (Hagil)	25
5	Bih	445
6	-	25
7	Naqab	65
8	Khatt, etc.	75
9	Mahani	90
10	Idhn	90
11	Sidr	50
12	Safsuf	75
13	Siji	142

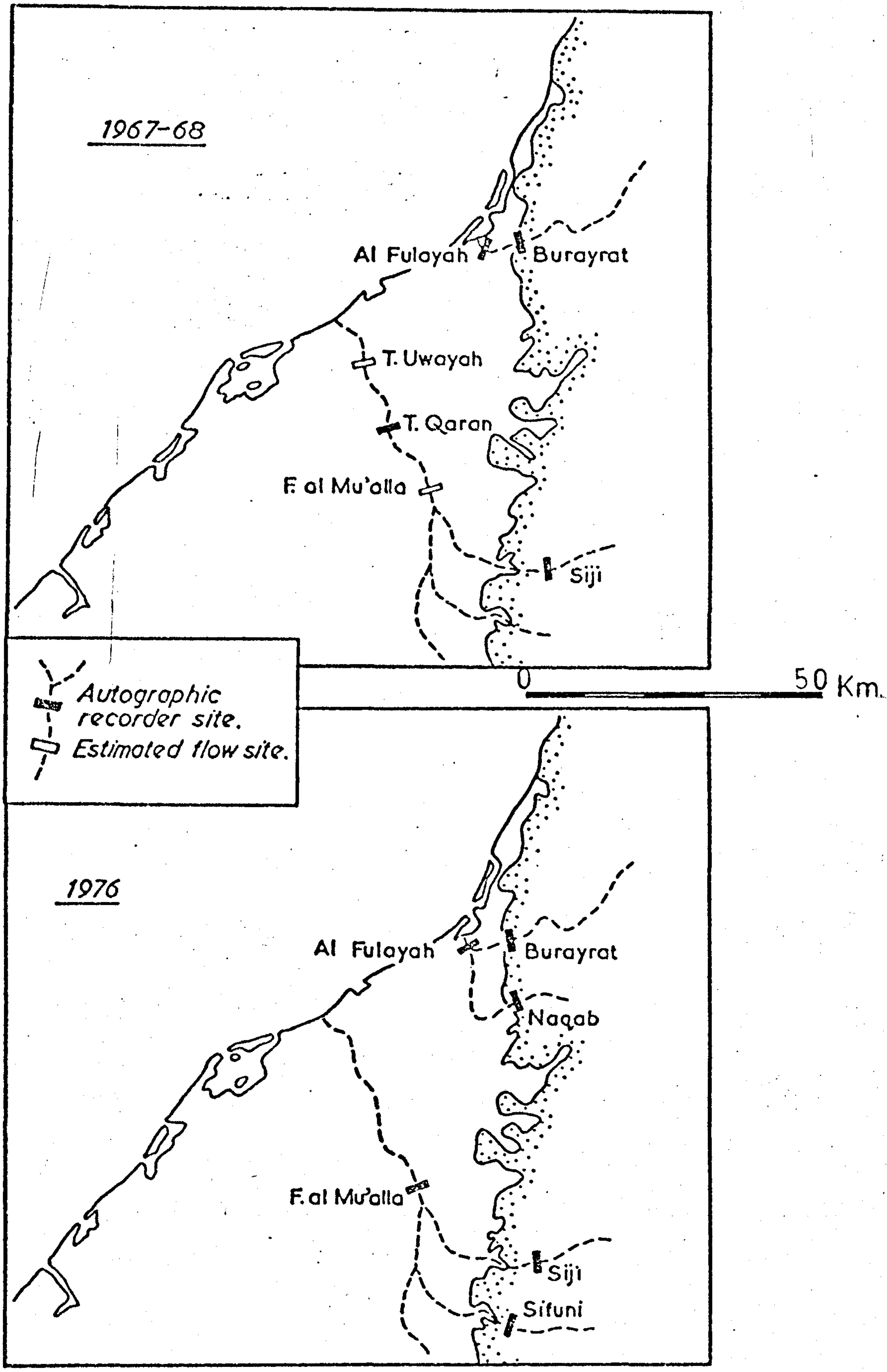


Fig. 5.2 Distribution of flood discharge gauges

flows on the gravel plains, have lost a considerable amount of their disch through infiltration along the wadi bed. They continue to lose water in crossing the plains and very rarely do such flows reach the coastline.

5.2 FLOOD DISCHARGES

In as much as no perennial streams are to be found in the area under investigation, the surface flow here considered is restricted to flood spates. The distribution of flood discharge recorder gauges in the study area is shown on Figure 5.2 and some details itemised below:-

Site	Wadi	Catchment (km^2)	Installation Date
Burayrat	Bih	478	1966; recommissioned Feb. 1976
al Fulayah	Bih	770	1966; recommissioned Nov. 1975
Naqab	Naqab	95	Feb. 1976
Siji	Siji	88	1966; recommissioned Feb. 1976
F. al Mu'alla	Lamhah	1484	1966; recommissioned Dec. 1975
Sifuni	Sifuni	140	Feb. 1976

It may be seen that four of the five existing gauging sites are at localities originally fitted in 1966 with Lea automatic recorders during the water resources survey undertaken by Halcrow's. These stations were operational during the hydrological years 1966-68; thereafter limitations on maintenance and personnel meant a break in the continuity of the record which was not restored until recommissioning of the stations in late 1975 or early 1976 with the present Leupold and Stevens one-year recorders fitted with four-month clocks. In all cases the float-operated autographic recorders were or are installed in chambers connected by buried pipes to the wadi bed, or in slotted vertical tubes sited adjacent to the edge of the wadi at a convenient point. The instruments record depth and duration of flow at the gauging site, and in conjunction with bed slope area, peak-flowrates can be determined and total flow volumes estimated. Rating curves are usually prepared from current meter measurements of flow velocity and water depth across the flooded section for use in conjunction with the flood stage levels, though this was not done until 1976.

During the period of the Halcrow survey (1966-68), rainfall was well below average (see Chapter 4) and details of the few occasions when flood spates were recorded at the gauging sites are reproduced in Table 5.2. Surface run-off in the abnormally dry years of 1966 and 1967 appears to have been negligible in most catchments and non-existent in the catchment of Wadi Bih. In 1968, however, flood spates were recorded and measured at all the stations fitted with recorders and was particularly marked in Burairat on the Wadi Bih and at Falaj al Mu'alla on the Wadi Lamhah, which drain very different types of catchment (see Table 5.3).

In the short period since recommissioning of the stations in 1975-76, wadi spates have been more frequent as is indicated by the data of Table 5.4 which represents a twelve-month period of recording. The more recent flow data take advantage of better recorders and the use of current metering as a standard procedure in the preparation of rating curves for discharge calculations. It should be noted that as with the Halcrow data, peak flow rates are estimated by the slope-area method using an assumed Manning roughness coefficient of 0·03 for all sites. Once a sufficiently large number of current meter measurements have been made over a range of discharges then a specific roughness coefficient can be calculated for each station site, and thus produce more accurate flow data. Inevitably, therefore, the data avalaible are indicative of frequency and order of magnitude of wadi flood spates rather than having precise significance.

It is well known in arid regions that so far as surface run-off is

Table 5.3: Flood discharges 1968-69.

Site	Wadi	Date	Peak flow (m^3/s)	Duration (hours)	Est. volume $x10^6$ m^3
Burairat	Bieh	9.12.68	47·3	12	1·020
		3. 1.69	small localised flow		
		7. 1.69	190·5	54	17·440
		10. 1.69	small localised flow		
		11. 1.69	small localised flow		
al Fulayah	Bieh	9.12.68	34·1	6	0·363
		7. 1.69	58·4	15	1·580
Siji	Siji	6.12.68	50·5	4	0·364
		9.12.68	10·5	5	0·095
		9.12.68	5·6	5	0·051
		7. 1.69	62·0	3	0·335
		9. 1.69	13·0	3	0·071
F. al Mu'alla	Lamhah	9.12.68	0·7	2	small
		10. 1.69	87·4	20	3·140
T. Qaran	Lamhah	10. 1.69	54·7	12	1·180

(Data from TSC, Hydrological Year Book, 1968-69)

Table 5.4: Wadi discharge data, July 1975 to June 1976

Wadi (site)	Date	Duration (days)	Discharge per flood ($m^3 x 10^3$)	Discharge per annum ($m^3 x 10^3$)
Bih (Al Fulayah)	1. 8.75	2	624·5	3493·3
	2. 2.76	1	6·2	
	3. 2.76	2	668·1	
	4. 3.76	2	42·6	
	5. 4.76	2	1442·2	
	5. 4.76	1	709·7	
Bih (Burairat)	1. 8.75	2	778·2	3049·8
	2. 2.76	1	52·4	
	3. 2.76	2	511·6	
	4. 3.76	2	39·4	
	5. 4.76	2	716·6	
	6. 4.76	1	951·6	
Naqab (Naqab)	1. 8.75	2	521·7	3921·8
	2. 2.76	1	89·4	
	3. 2.76	1	1949·3	
	4. 3.76	2	147·1	
	5. 4.76	1	1157·9	
	6. 4.76	1	56·4	
Lamhah (F. al Mu'alla)	1. 8.76	1	8·7	496·1
	2. 2.76	2	47·2	
	3. 4.76	2	440·2	
Siji (Siji)	1. 8.75	24	1735·2	4317·8
	2. 2.76	7	765·9	
	3. 2.76	45	457·4	
	4. 4.76	59	1359·3	

(Data from UAE Ministry of Agriculture, 1977) concerned, the intensity of rainfall is more important than the total amount of rainfall. When the rainfall is evenly distributed in time and area there may well be no resultant run-off, whereas even in a less than average rainfall-year, severe flooding can result from one or two rainstorms of exceptional intensity.

One method commonly used to derive flood hydrographs for areas having limited information is to prepare the theoretical hydrograph for a storm of unit precipitation in unit time. This 'unit hydrograph' can then be scaled to correspond to any given rainfall pattern. Some of the parameters necessary for preparation of the 'unitgraph' are:-

A = drainage area (km^2)
L = length of drainage channel (km)
H = change in elevation (m)
D = effective rain period (hr)
T_c = time of run-off concentration (hours) $= \left(\frac{0{\cdot}87\ L^3}{H} \right)^{0{\cdot}385}$

The unit hydrograph can be approximated by a triangle having three parameters in common with the true hydrograph, namely the peak rate (q_p), the time to peak (T_p) and the total volume of run-off (Q) each of which can be determined by use of the following standard equations:

$$Tp\ (hr) = \frac{D}{2} + 0{\cdot}6\ T_c$$

$$q_p\ (m^3/sec) = \frac{0{\cdot}2085\ AQ}{T_p}$$

$$T_p\ (hr) = 2{\cdot}67\ T_c = \text{time base of unit hydrograph}$$

The unit precipitation is arbitrarily chosen as 20 mm in a unit time of 10 minutes, and the estimated resultant parameters for the Bin and Siji catchments to the respective gauges at Burayrat and Siji are tabulated below:-

Catchment	A	L	H	Tc	Tp	Tb	q_p
Bih	480	40	2000	3·6	2·3	6·1	1093
Siji	100	15	1000	1·5	1·0	2·8	506

The synthetic unit hydrograph for each catchment based on the derived data would have the form illustrated in Figure 5.3. Although there is insufficient rainfall data to quantify the largest storm likely to occur in either area, two such storm conditions have been arbitrarily selected. One with a rainfall of 50 mm/hour has a probable frequency of 1 in 5 years while the other at 100 mm/hour would be 1 in 30 years or greater. Some allowance needs to be made to take account of the non-uniform areal and time distribution of any rainfall. Areal factors of 0·6 and 0·7 were chosen for the Bih and Siji catchments respectively to give reduced values. The predominant pattern of rainfall of interest to this study is that provided by individual thunderstorms which it is assumed correspond to the idealised one hour rainfall pattern broken into ten minute increments as indicated below:

Time from start of storm (min)	Proportion of 1 hour rainstorm	Increment (mm)			
		'50 mm storm'		'100 mm storm'	
		Bih	Siji	Bih	Siji
0	0	0	0	0	0
10	0·05	1·5	1·75	3·0	3·0
20	0·10	3·0	3·5	6·0	7·0
30	0·15	4·5	5·25	9·0	10·5
40	0·20	6·0	7·0	12·0	14·0
50	0·40	12·0	14·0	24·0	28·0
60	0·10	3·0	3·5	6·0	7·0

The theoretical breakdown of rainfall increments during the storm event will be disposed of according to the physical characteristics of the catchments. These have been assumed to bear comparison with the series of standard rainfall - direct run-off curves prepared bythe US Department of Agriculture; Bih has been assigned curve number 90 and Siji that of curve number 85 as indicated in Figure 5.3(b).

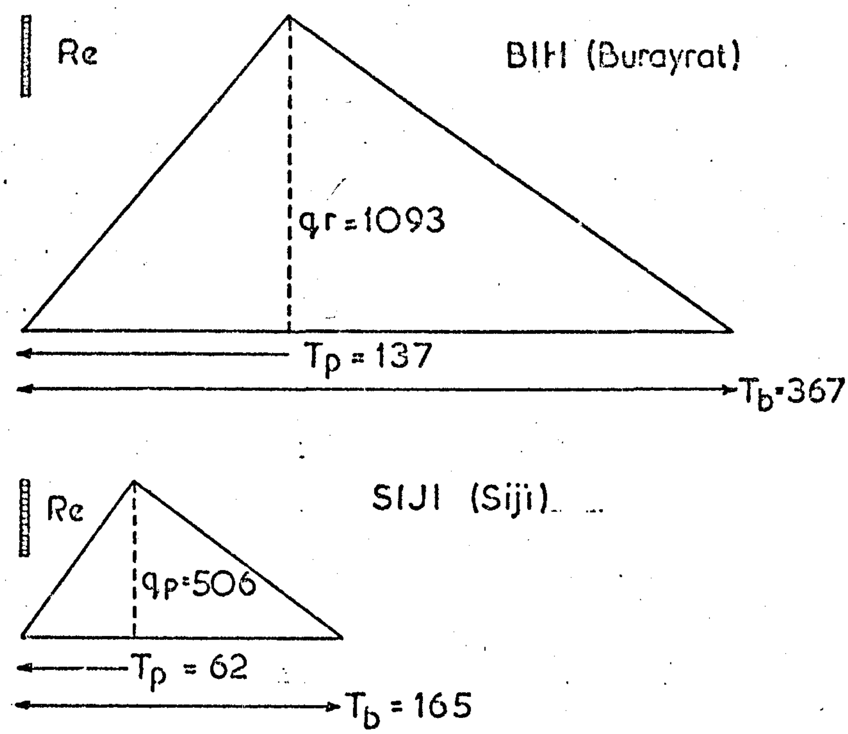


Fig. 5.3 (a) Synthetic unit hydrograph for wadis Bih and Siji

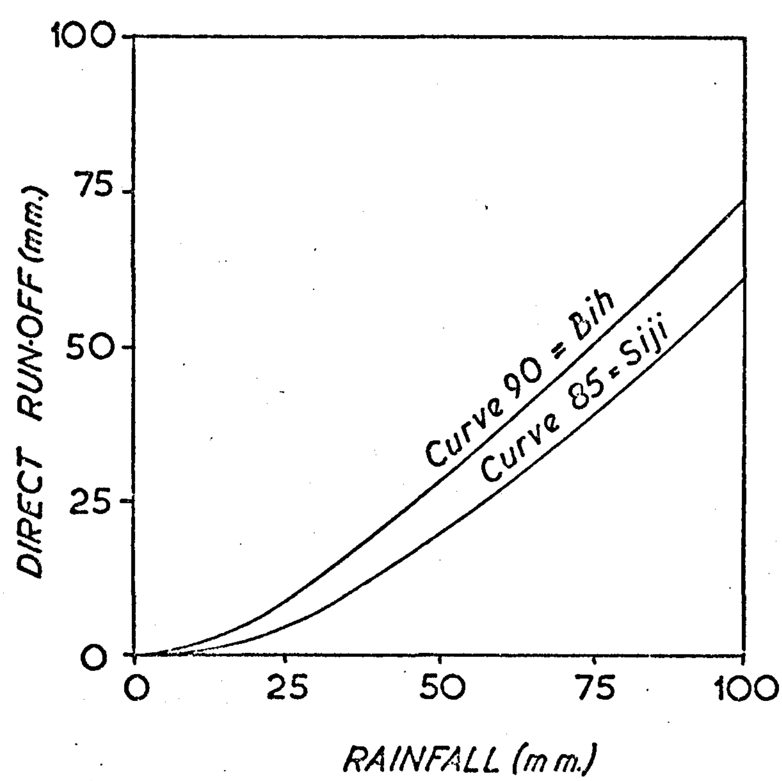


Fig. 5.3 (b) Standard rainfall run-off curves (after US Dept. Agric.)

The relevant calculations are given in Table 5.5 for incremental run-off under the unit graph conditions for both catchments, and in Table 5.6 the incremental run-off has been scaled to take account of the characteristics of the catchment. The pairs of hydrographs representing the '50 mm storm' and the '100 mm storm' for the Bih and Siji catchments are given in Figures 5.4 and 5.5 respectively.

Table 5.2: Wadi spate flows 1965 - 1968.

Site	Wadi	Date	Peak flow (m^3/s)	Duration (hours)	Est. volume $x10^6$ m^3
Burairat	Bih	(no recorded flow during 1965-66; 1966-67)			
		2. 2.68	108·5	84	16·080
al Fulayah	Bih	(no recorded flow during 1965-66; 1966-67)			
		2. 2.68	27·7	12	0·745
Siji	Siji	5. 2.66	84·4*	-	-
		8.10.66	5·4	12	0·116
		29. 3.67	39·3	12	0·847
		27. 7.67	39·3	5	0·035
		12. 8.67	12·1	4	0·087
		23.10.68	7·0	1·5	0·019
		2. 2.68	12·9	2·5	0·058
		3. 8.68	93·5	4	0·672
F. al Mu'alla	Lamhah	5. 2.66	2·6*	-	-
		8.10.66	3·5	2	0·013
		2. 2.68	159·0	24	7·720
Qaran	Lamhah	5. 2.66	0·9*	-	-
		5. 2.68	0·9	-	-
		2. 2.68	68·5	20	2·480

* estimates obtained by surveys of the channel and levels of trash marks at the gauging sites.

(Data from SWH (1959))

Table 5.5: Calculations for incremental run-off.

Storm	Time from start to storm (mm)	Increm. of rainfall (mm)	Accum. rainfall (mm)	Accum. direct run-off (mm)	Increm. direct run-off (mm)	Increm. loss to soil (mm)
	BIH (Burairat)					
'50 mm storm'	0	0	0	0	0	0
	10	1·5	1·5	0	0	1·5
	20	3·0	4·5	0	0	3·0
	30	4·5	9·0	1·0	1·0	3·5
	40	6·0	15·0	3·75	2·75	3·25
	50	12·0	27·0	10·0	6·25	5·75
	60	3·0	30·0	12·5	2·5	0·5
'100 mm storm'	0	0	0	0	0	0
	10	3·0	0	0	0	3·0
	20	6·0	9·0	1	1	5·0
	30	9·0	18·0	4	3	6·0
	40	12·0	30·0	12·5	8·5	3·5
	50	24·0	54·0	32·0	19·5	4·5
	60	6·0	60·0	36·0	4·0	2·0
	SIJI (Siji)					
'50 mm storm'	0	0	0	0	0	0
	10	1·75	1·75	0	0	1·75
	20	3·5	5·25	0	0	3·5
	30	5·25	10·5	1·25	1·25	4·0
	40	7·0	17·5	2·5	1·25	5·75
	50	14·0	31·5	7·5	5·0	9·0
	60	3·5	35·0	10·0	2·5	1·0
'100 mm storm'	0	0	0	0	0	0
	10	3·5	3·5	0	0	3·5
	20	7·0	10·5	1·25	1·25	5·75
	30	10·5	21·0	3·75	2·5	8·0
	40	14·0	35·0	10·0	6·25	7·75
	50	28·0	63·0	28·75	18·75	9·25
	60	7·0	70·0	35·0	6·25	0·75

Table 5.6: Scaled run-off calculations for representative catchments.

Storm	Time since start (min)	Increm. runoff (mm)	Unit q_p (m^3/s)	Actual q_p m^3/s)	Start time (min)	Peak time (min)	End time (min)
BJH (Burairat)							
'50 mm storm'	10	0	1093	0	0	138	366
	20	0	1093	0	10	148	376
	30	1	1093	55	20	158	386
	40	2·75	1093	151	30	168	396
	50	6·25	1093	344	40	178	406
	60	2·5	1093	138	50	188	416
'100 mm storm'	10	0	1093	0	as for above storm		
	20	1	1093	55			
	30	3	1093	165			
	40	8·5	1093	468			
	50	19·5	1093	1073			
	60	4	1093	220			
SIJI (Siji)							
'50 mm storm'	10	0	506	0	as for above storm		
	20	0	506	0			
	30	1·25	506	30			
	40	1·25	506	30			
	50	5·0	506	125			
	60	2·5	506	60			
'100 mm storm'	10	0	506	0	as for above storm		
	20	1·25	506	30			
	30	2·5	506	60			
	40	6·25	506	155			
	50	18·75	506	470			
	60	6·25	506	155			

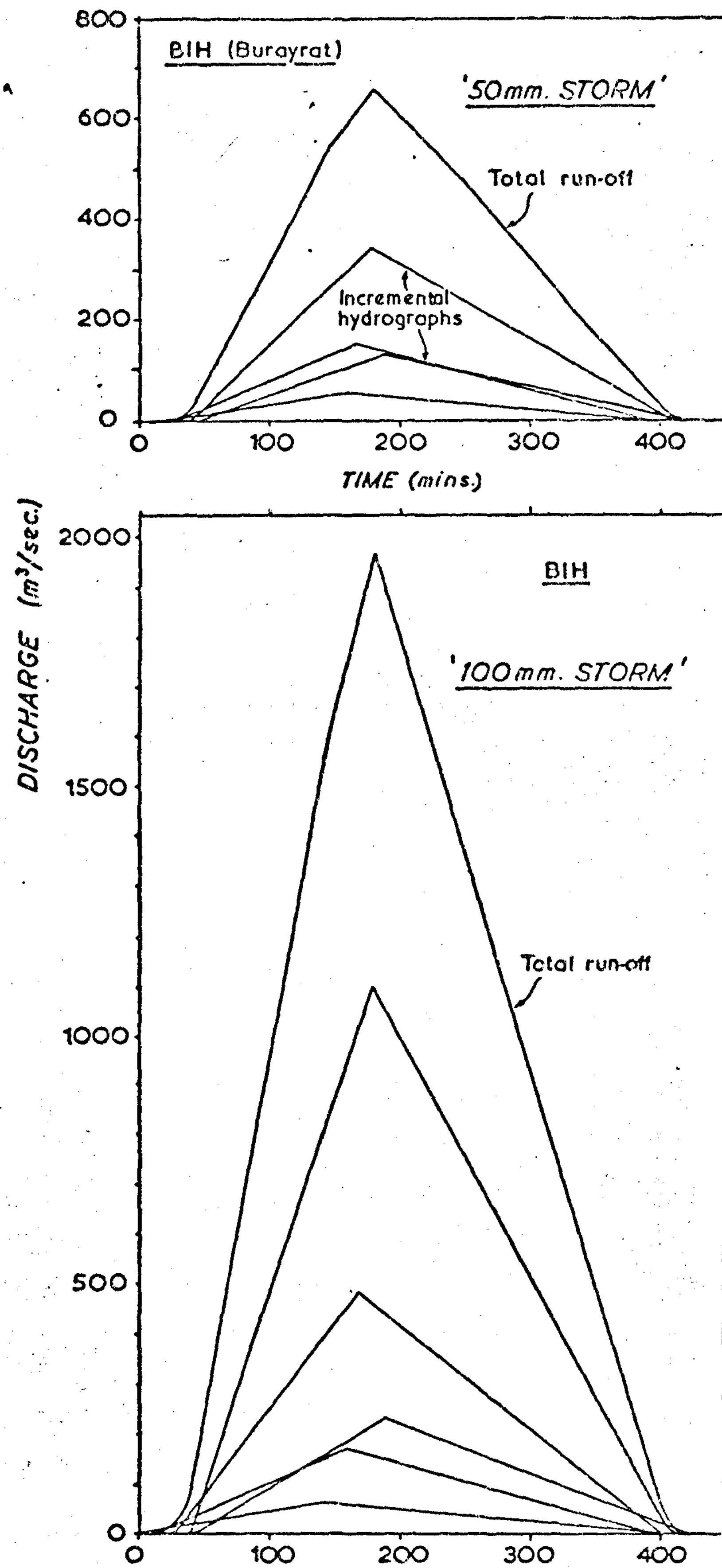


Fig. 5.4 "50 mm" and "100 mm" storm hydrographs for Wadi Bih at Burayrat.

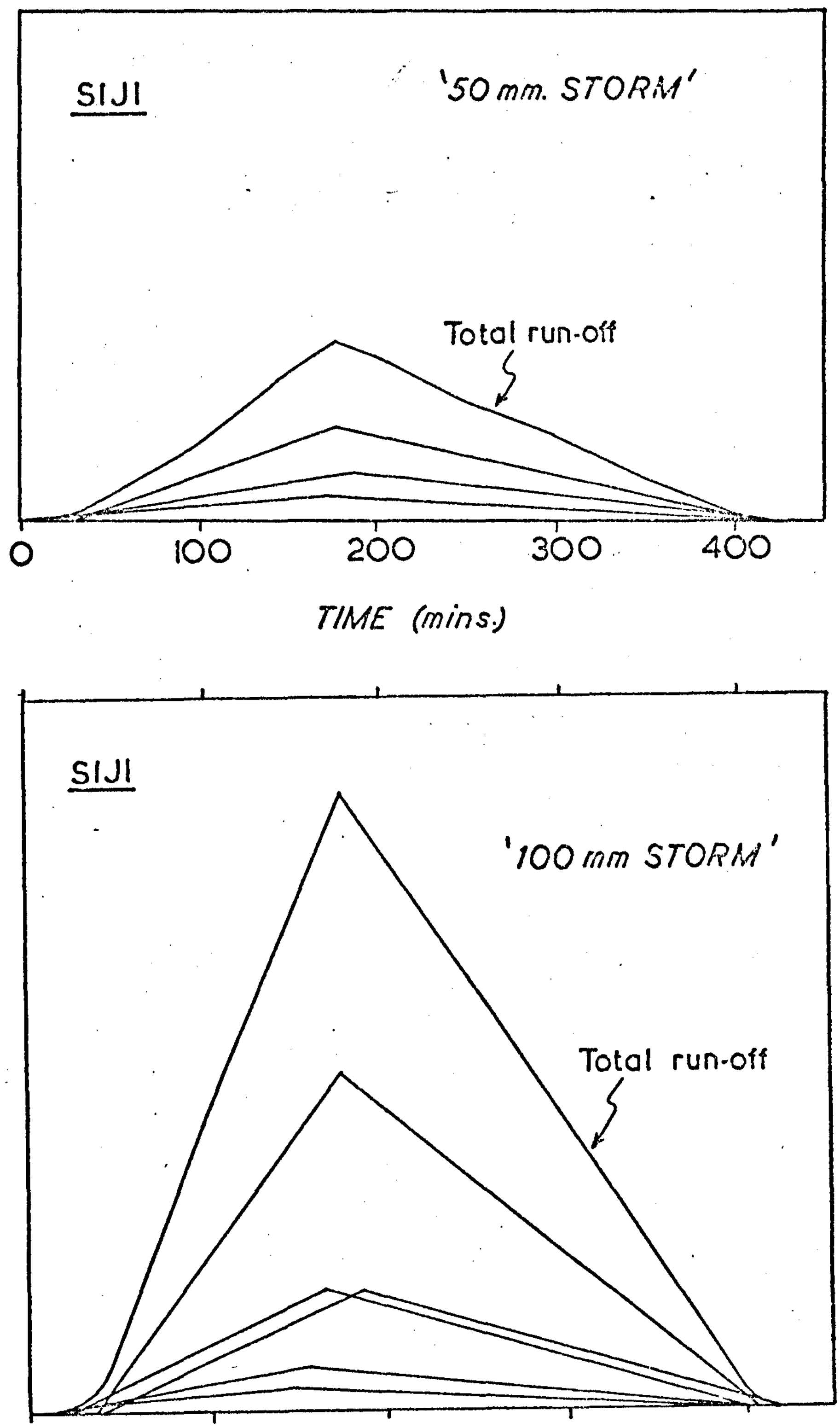


Fig. 5.5 "50 mm" and "100 mm" storm hydrographs for Wadi Siji at Siji.

6. HYDROGEOLOGY

6. HYDROGEOLOGY

6.1 HYDROGEOLOGICAL UNITS

The physiographic units identified in Figure 3.1 and used in previous chapters also provide distinctive hydrogeological units which will subsequently be demonstrated to have characteristics of particular relevance to practical ground water investigations. The ground water units are Coastal Flats, Dune Sands, Gravel Plain (North), Gravel Plain (South), Mountain (North) and Mountain (South) and are diagrammatically illustrated in Figure 6.1.

Division of the Gravel Plain and Mountain Units into northerly and southerly portions coincides with the general line of the Dibba Fault area and its extension to the west. It will be remembered from the description of the geology of the study area that such a division had direct meaning in the Mountain area by separating a dominantly limestone and dolomite area in the north from the complex turbidite and serpentinite basic rock sequences to the south. The division of the Gravel Plain reflects the same distribution since it assumes that the constituent fragments of the gravel have been derived in geologically Recent times from the rocks that currently lie immediately east.

Of the remaining units, the coastal fringe of Sabkha and tidal flats has no direct positive value to water resources since the waters it contains are much too saline to have any practical use. Nevertheless, its importance as a hydrogeological unit does have a negative impact since it extends further inland the saline-fresh water interface which normally is positioned at the coastline.

In the Dune Sands unit, the blanket of Recent sand serves to retard such occasional natural replenishment as may occur, except in the vicinity of the larger deflation areas where ready access is provided to the underlying gravels.

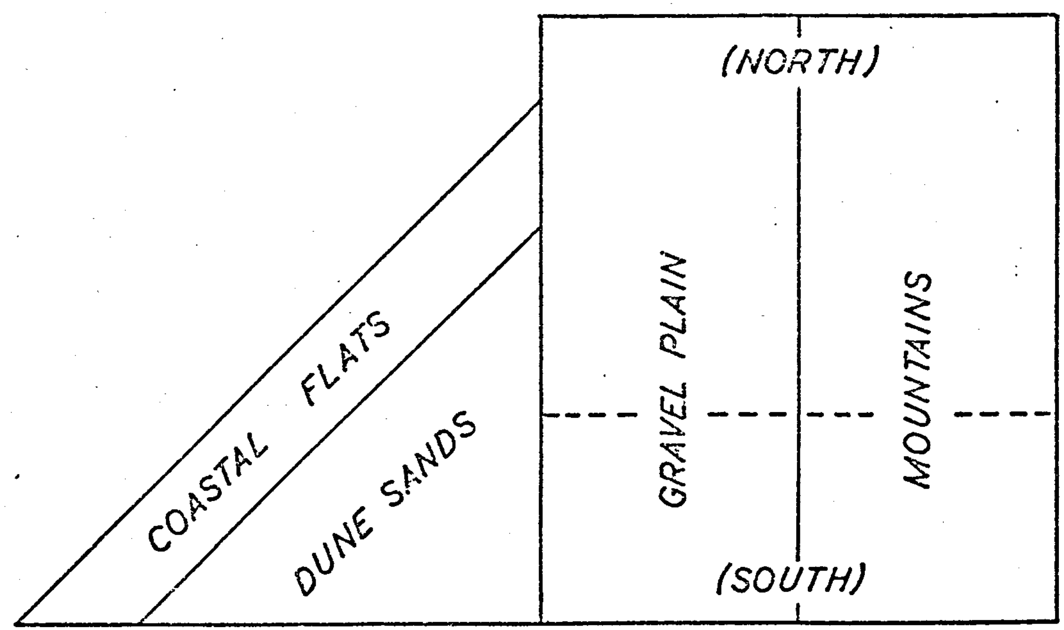
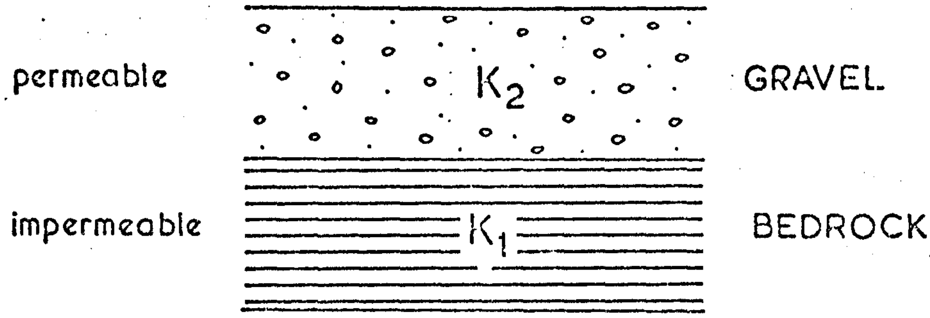
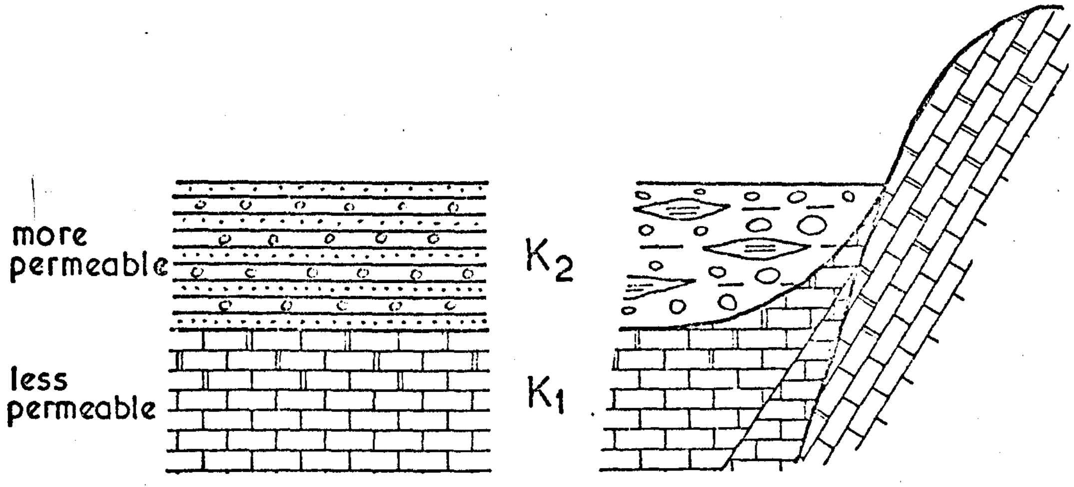


Fig. 6.1 Schematic illustration of ground water units.



(a) traditional aquifer model



(b) proposed layered aquifer model

Fig. 6.2 Graphical representation of alternative conceptual models for the aquifer system in northern UAE.

6.2 AQUIFER LIMITS AND CHARACTERISTICS

In theory an aquifer may be regarded as a lithological formation or group of formations that is able both to transmit and store water. Two further functions are the provision of an intake area and the ability under favourable conditions to act as a natural treatment plant. It is, however, rare that an aquifer fulfils all four functions simultaneously.

In practice the aquifer system comprises a layered sequence with each layer having different characteristics of thickness, nature, extent and hydraulic properties. The gravels and sands have long been regarded as the sole aquifer in the study area with only minor or negligible yields associated with the harder rocks of the mountain region. Given the non-availability of deep water wells and a distinct paucity of information from the oil exploration companies regarding the prospects of good yields from deeper strata, it is understandable that attention should have been wholly directed towards the relatively shallow unconsolidated deposits in the search for and development of underground water resources. The conceptual ground water model for these conditions is represented in Figure 6.2(a) as a simple case of an isotropic, permeable aquifer overlying a non-isotropic impermeable aquiclude.

The proposed layered aquifer model would accept a gross two-fold division wherein a permeable sequence overlies a less permeable sequence as illustrated schematically in Figure 6.2(b). In the Gravel Plain (North) unit, permeable unconsolidated gravels with sand and silt layers are presumed to overlie less permeable fissured carbonate rocks and marls comparable to those cropping out in the Mountain (North) unit. The gravel aquifer north of the Dibba Line has a gently sloping surface extending from the wadi mouths and alluvial fans (Photo. 2.1, 2.2, 6.3 and 6.4) which has a tendency to become less coarse in a westerly direction away from the provenance of the detritus. In the Gravel Plain (South) unit, the unconsolidated gravels are thin and the hydrogeologicall important materials are the conglomerates of mudflow origin

Photo. 6.1: Gently sloping upper part of alluvial fan near mouth of Wadi Bih.

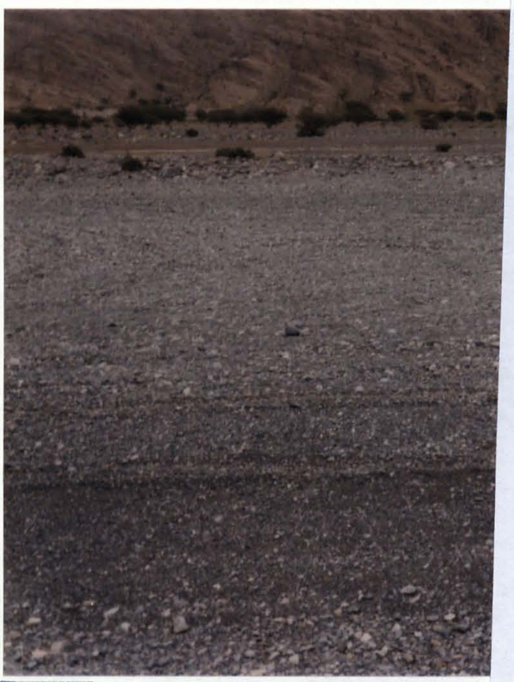


Photo. 6.2: Extensive gravel spreads in Wadi Bih.

Photo. 6.3: Gravel material near Khatt

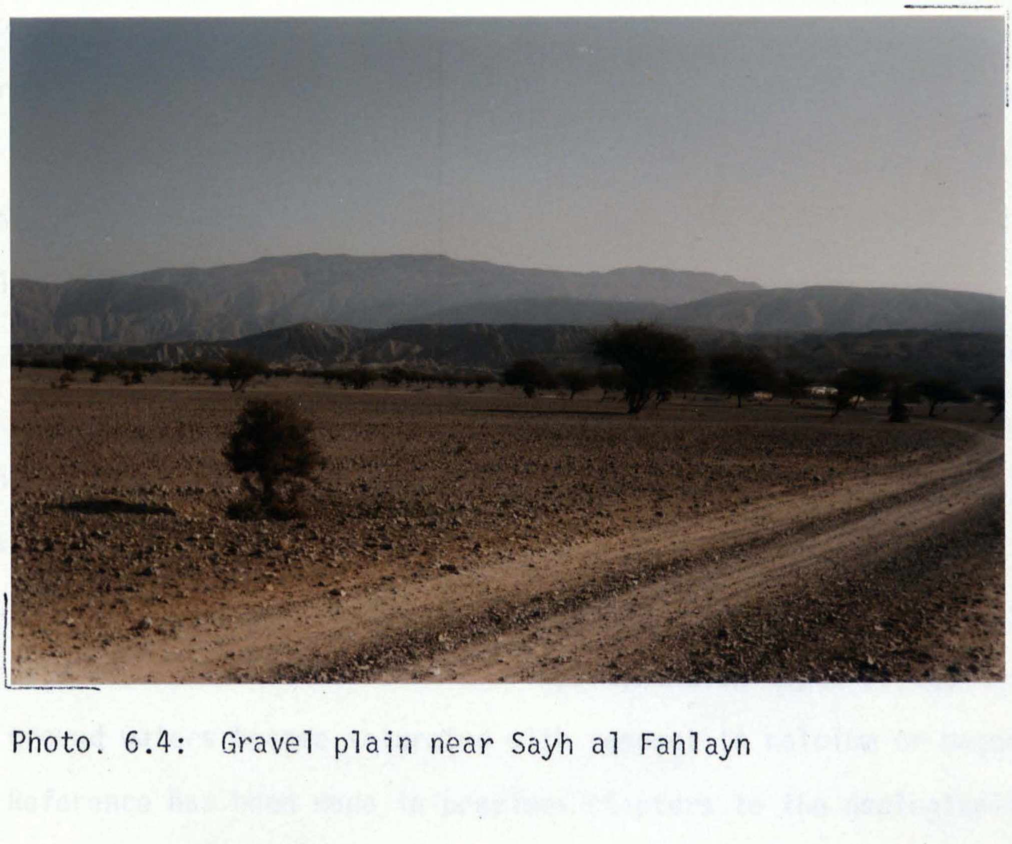


Photo. 6.4: Gravel plain near Sayh al Fahlayn

(equivalent to boulder beds of Tertiary age at the western edge of the mountain) and the less permeable underlying ? Tertiary dolomites and Maestrichtian limestones.

Enclosure 6.1 graphically depicts the lithological sequences at six borehole sites extending from Sha'am in the north to Falaj al Mu'alla in the south. The northern three are located in the Gravel Plain area while the southern three are sited on the Dune Sand unit as well as the Gravel Plain (South). The depths of the boreholes range from 50 m to about 80 m, but in no case was the gravel and sand aquifer fully penetrated, nor was it possible to correlate layers from one borehole to another on the basis of the driller's logs. This identifies two of the major deficiencies in knowledge of aquifer characteristics in the study area. Firstly, the total depth to the base of the aquifer remains unknown so that one can only guess the thickness of the saturated part of the aquifer. Secondly, the preferred method of rotary drilling with mud makes difficult the identification of lithological details in what is in any case a layered and lenticular sequence, and no borehole logging information is available for guidance and confirmation.

Similarly, all that is known about the presumed underlying carbonates and marls is by comparison with outcrops of similar strata at the edges of the mountain range to the east. They are thick, well-bedded sequences folded asymmetrically along N - S axes and with the resultant fracture pattern modified by faulting and thrusting (Photos. 6.5 and 6.6). In detail, the bedding and fracture planes have provided access for ground water movement so that much preferential solution has taken place and produced the type of solution channels illustrated in Photographs 6.7 and 6.8.

Such solution is likely to have been prevalent in the upper parts of the carbonate sequence and would have been less important with depth as the percolating ground waters became saturated with respect to calcium or magnesium carbonate. Reference has been made in previous chapters to the geologically

Photo. 6.5: Thick sequences of Ghalilah Formation (Triassic) in Wadi Rahaba.

Photo. 6.6: Well-bedded sequence of Musandam Formation (Jur-Cret) in Wadi Hark.

Photo. 6.7: Massively bedded limestones with indications of solution along bedding planes and joints.

Photo. 6.8: More detail of solution channels in limestone sequence at Wadi Rahaba.

Recent uplift of parts of the study area, and one must accept as a distinct possibility that the parts having greatest solution and therefore greatest permeability have been raised to elevations above the present day water table. Nevertheless, justification for consideration of the carbonate sequences as potential sources of water supply can be made by comparison with similar sequences in Oman, Kuwait and Saudi Arabia, and certainly they warrant more attention than has been given to them previously.

6.3 AQUIFER PROPERTIES

The hydraulic properties of aquifer systems that usually have most significance for water resources studies are those related to the ability of the aquifer to transmit through or store water in their interconnected voids. The definitions of the commonly used terms were made with idealised porous-media conditions in mind so that in the UAE they are most applicable to granular sequences and less applicable to carbonate sequences with only few preferred solution channels. A list of the more relevant aquifer properties used in this section is given in Table 6.1, with their appropriate symbols and units.

The unconsolidated deposits that comprise the predominant aquifer make up a multi-layered complex of permeable and impermeable strata. Such individual units vary greatly in thickness and lithology but are considered to be in hydraulic continuity with one another. Under such conditions, any laboratory determinations of permeability would be viewed with suspicion, and field testing with or without an observation well becomes the only reliable means of quantifying the more important hydraulic properties.

Although in the past such testing may have consisted of no more than pumping or baling at a single rate for a relatively short duration of time, it is believed that the present system is thorough and up-to-date in its aims and procedures. A step-drawdown test with three or four stages taken to equilibrium usually precedes a constant rate test of 24 to 48 hours duration followed by recovery. It should be remembered that the drilling companies

Term	Symbol	Unit
Hydraulic conductivity	K	$m^3/day/m^2$
Intrinsic permeability	K	darcies
Transmissivity	T	$m^3/day/m$
Storativity	S	m^3/m^3
Hydraulic conductivity of aquiclude	K'	$m^3/day/m^2$
Saturated thickness of aquifer	b	m
Saturated thickness of aquiclude	b'	m
Leakance of aquiclude	K'/b'	$m^3/day/m^3$
Leakage factor of aquiclude	L	m
Specific yield	Sy	m^3/m^3
Drainage factor of aquifer	D	m
Drainage delay index	1/a	days
Radial distance to observation well	r	m

Table 6.1 Relevant aquifer properties and characteristics

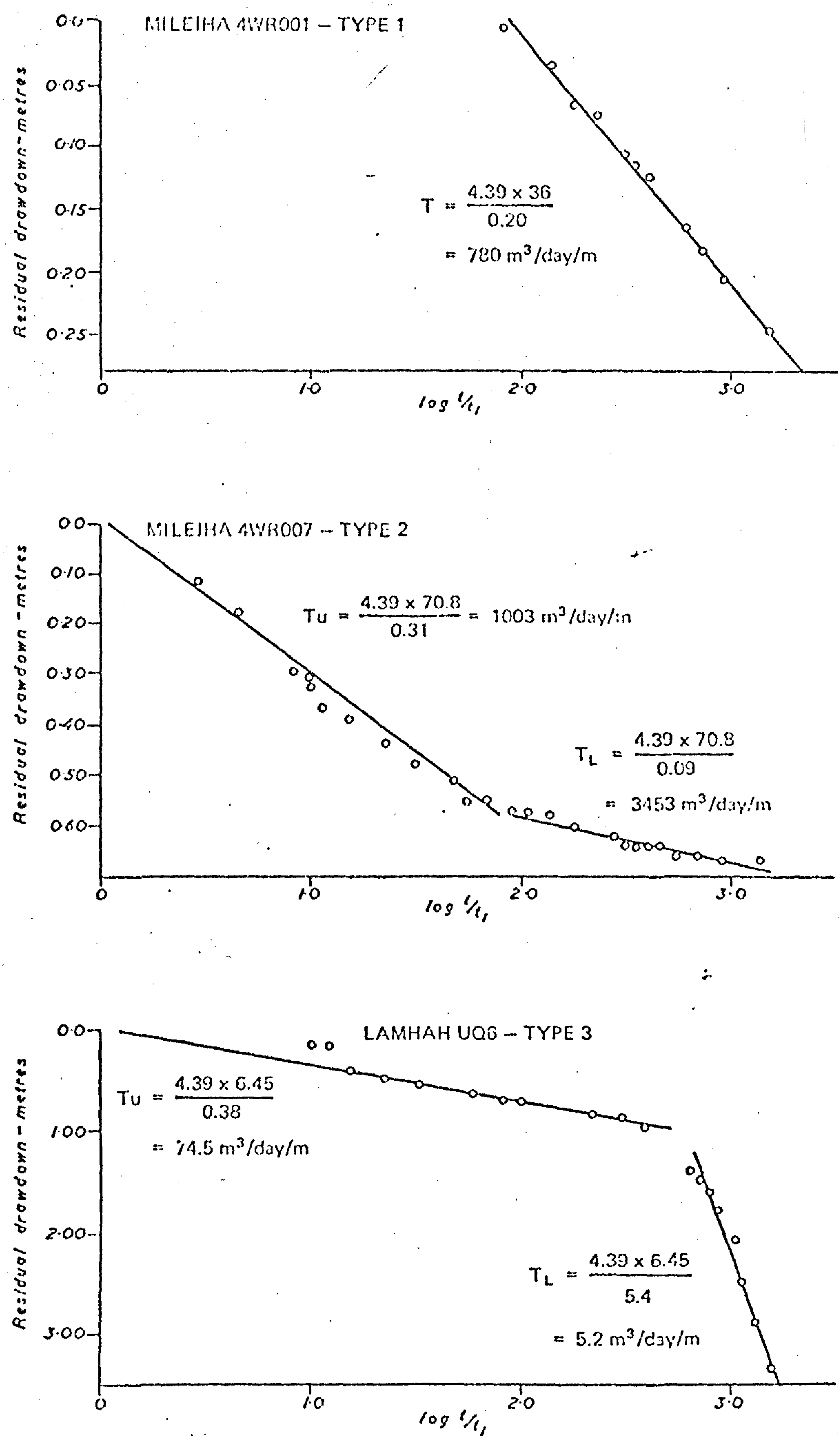


Fig. 6.3 Typical recovery curves

Location	Ref. No.	Depth (ft)	Dia (in)	Date	Depth to swl (m)	Pumping rate (m^3/h)	Drawdown (m)
Burairat (MEW)	1	250	10	4.3.76	54.74	55.0	3.12
Burairat (MEW)	2	250	12¾	25.4.76	47.61	31.0	1.03
Burairat (MEW)	3	250	12¾	14.5.76	50.72	31.0	2.76
Burairat (MEW)	4	250	12¾	18.5.76	53.10	31.0	3.61
Burairat (MEW)	5	250	10	5.7.76	53.42	75.0	1.90
Burairat (MEW)	6	250	10	20.7.76	52.18	70.0	4.09
Satellite Sta.	1	250	17½	May '76	-	30.9	3.53
RAK Airport	1	190	-	1976	-	-	-
RAK Airport	2	190	-	1976	-	-	-
Burairat (RAK)	1	306	17½	1976	56.45	36.0	1.31
Burairat (RAK)	2	245	17½	1976	54.59	34.0	1.27
Burairat (RAK)	3	300	17.	1976	54.36	37.0	1.46
Burairat (RAK	4	300	17½	1976	53.90	35.0	1.28
Burairat (RAK)	5	300	17½	1976	53.76	33.0	1.19
Burairat (RAK)	6	300	17½	1976	54.26	34.0	1.21

Table 6.2 Details of production wells drilled during period of study project.

are concerned with commercial practices, and since most clients are interested solely in well yields rather than data collection for scientific purposes, it is only infrequently possible to obtain all the desired information.

Such test data as were available prior to initiation of the study project, although apparently numerous, were not gathered with modern test procedures. Table 6.2 lists the wells drilled and tested during the study period and provides the source for the more meaningful analysis of pumping test data.

In their detailed report of 1969, Sir William Halcrow & Partners (SWH) undertook many pumping tests of short duration and observed that "transmissivities ranged from 3·3 $m^3/d/m$ to nearly 20,000 $m^3/d/m$". The upper end of this range is so high as to warrant suspicion and justified further study of their method of analysis. Because most of the boreholes were too far removed from existing holes for the latter to be used as observation points SWH apparently ignored the drawdown data in the pumped wells, and relied exclusively on 'recovery' data for their determination of aquifer properties. Such data are notoriously difficult to interpret in the absence of complementary drawdown data, and SWH themselves noted that three alternative types of graphs were common as illustrated in Fig. 6.3.

Examination was made of the data plots for all wells tested from the present study area. Some of the information was considered inadequate and their calculated transmissivity values were thus discarded. A possible error in the plotting and interpretation of the data was suggested in some cases by the plotting of residual drawdown for values of t/t' less than 1·0. Since t = time since pumping started and t' = time since pumping stopped, then it is obvious that t' will always be smaller than t and no matter how long the period of recovery there can be no values for t/t' less than 1. Some of the SWH data plots of this kind are shown in Fig. 6.4, and may be seen to include the suspiciously high value for transmissivity of 19,865 $m^3/d/m$.

From copies of the SWH basic field test data provided by the UAE Federal

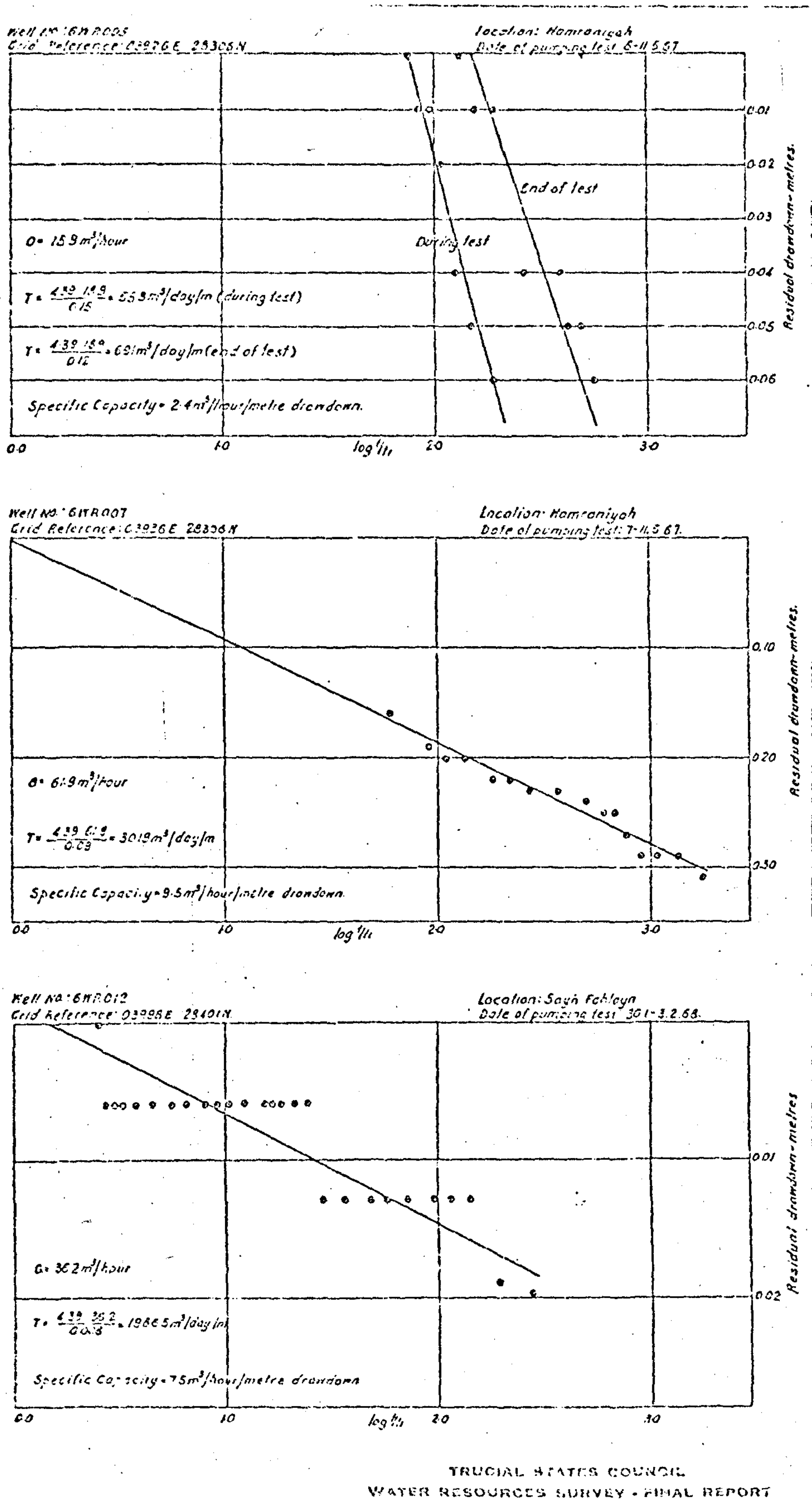


Fig. 6.4 Examples of SWH recovery data plots

Ministry for Electricity and Water it was possible to plot and analyse data from some of the more critical localities within the study area so as to verify the SWH results. The replotting of three data sets (Appendix Ia) was considered sufficient as a comparative exercise and in all cases both drawdown and recovery data were analysed. The straight-line method described by Cooper and Jacob (1946) was adopted because the quality of the test data did not appear to be good enough to allow use of the type curve method, and was in any case restricted to the pumping well.

In using the straight-line method one needs to be aware of the limitations of the equations used, which are modifications of those of Theis (1934) and thus subject to all of the constraints applicable to the ideal confined aquifer for which the original equations were derived. These are detailed in most text books on the subject (e.g. Walton, 1970; Kruseman and de Ridder, 1970) and need not be reproduced here in elaboration of the equations, which expressed in consistent units are:-

$$T = \frac{0.183\ Q}{\Delta s}$$

where T = transmissivity
Q = constant discharge rate
Δs = change water level per log cycle

and

$$S = \frac{2.25 T t_0}{r^2}$$

where S = storativity
t_0 = time intercept
r = radial distance to observation point

The method also requires that $u = r^2S/Tt$ is sufficiently small (i.e. <0.01) before the test data can be fitted to the ideal single straight line, but rarely is this retrospective check undertaken. Furthermore, when the method is applied to water table rather than confined aquifers, then one should expect not one but three straight lines with different slopes. These represent changes in aquifer response as falling water levels are affected by the delay due to gravity drainage. The typical three-segment plot with segments 1 and 3 having a similar slope steeper than that of segment 2, will be produced only when the duration of testing at a constant rate is prolonged well beyond the termination of drainage due to dewatering of part of the aquifer. Finally, an implicit assumption that the pumping well is 100 percent efficient is rarely valid, and water level measurements inside the pumping well could lead to significant errors where well-losses are substantial.

The addition of drawdown plots and interpretation provides essential confirmation in the analysis of the more reliable recovery data, and also serves to highlight some of the problems associated with test pumping and data analysis. For example, the data from well 4WR-033 produces greater transmissivity (T) values during recovery than drawdown, but in any case does not appear to have continued pumping long enough to extend beyond segment 2 (Fig.6.5). Well 4R-032 has a very low yield but produces three segments, though the third drawdown segment suggests that cessation of pumping in a nearby well might have been the cause of the anomalous rising water levels since the record shows that the discharge rate was checked a number of times during this period without any diminution in the yield of 7·6 m^3/h (Fig.6.6). The recovery data from this well have only two segments and those used by SWH seem by comparison with the drawdown data to reflect gravity drainage so that the results from this site must be considered very doubtful. Well 6WR-015 provides a good example of three segments from both drawdown and recovery data, though some interpolation is necessary to deduce the drawdown tail in Figure 6.7. The comparative results are tabulated below:-

Well number	Q (m^3/h)	SWH T (rec)	reinterpretation T (d-d)	reinterpretation T (rec)
4 WR-033	50·3	2208	550	1100
4 WR-032	7·6	59·6	?	?
6 WR-015	30·4	360	300	220

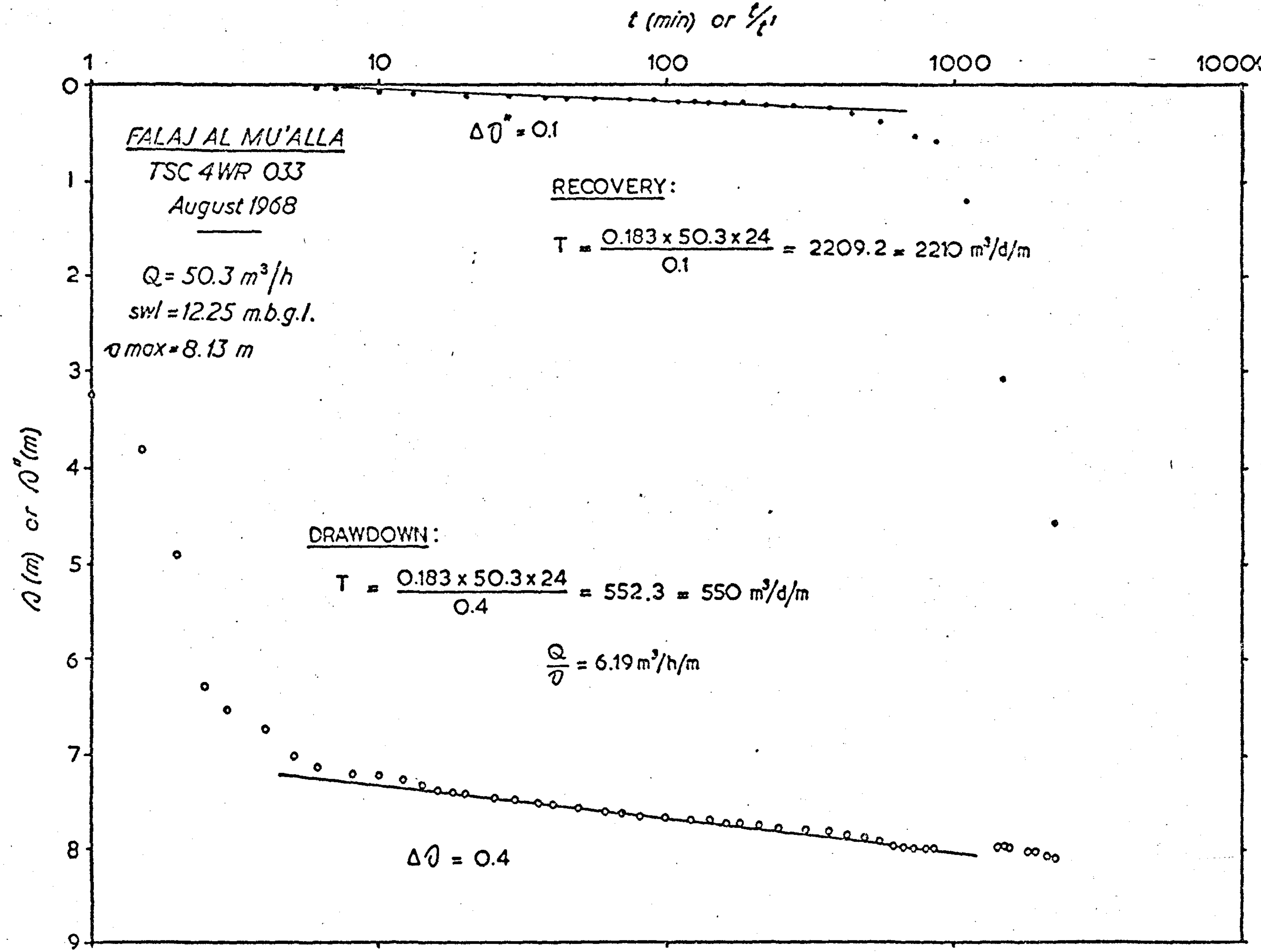


Fig. 6.5 Drawdown and recovery data plot for Well 4WR-033

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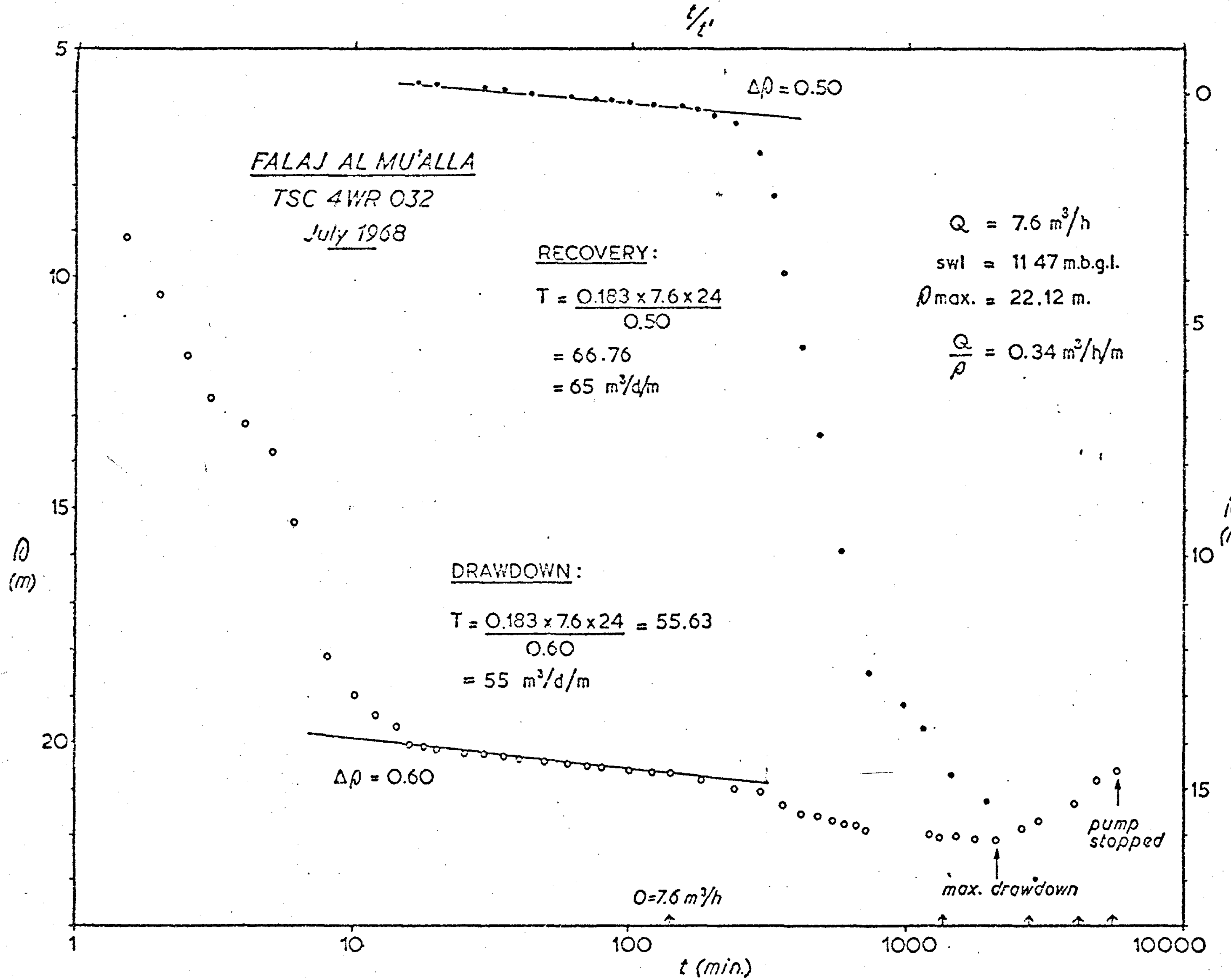


Fig. 6.6 Drawdown and recovery data plot for Well 4WR-032

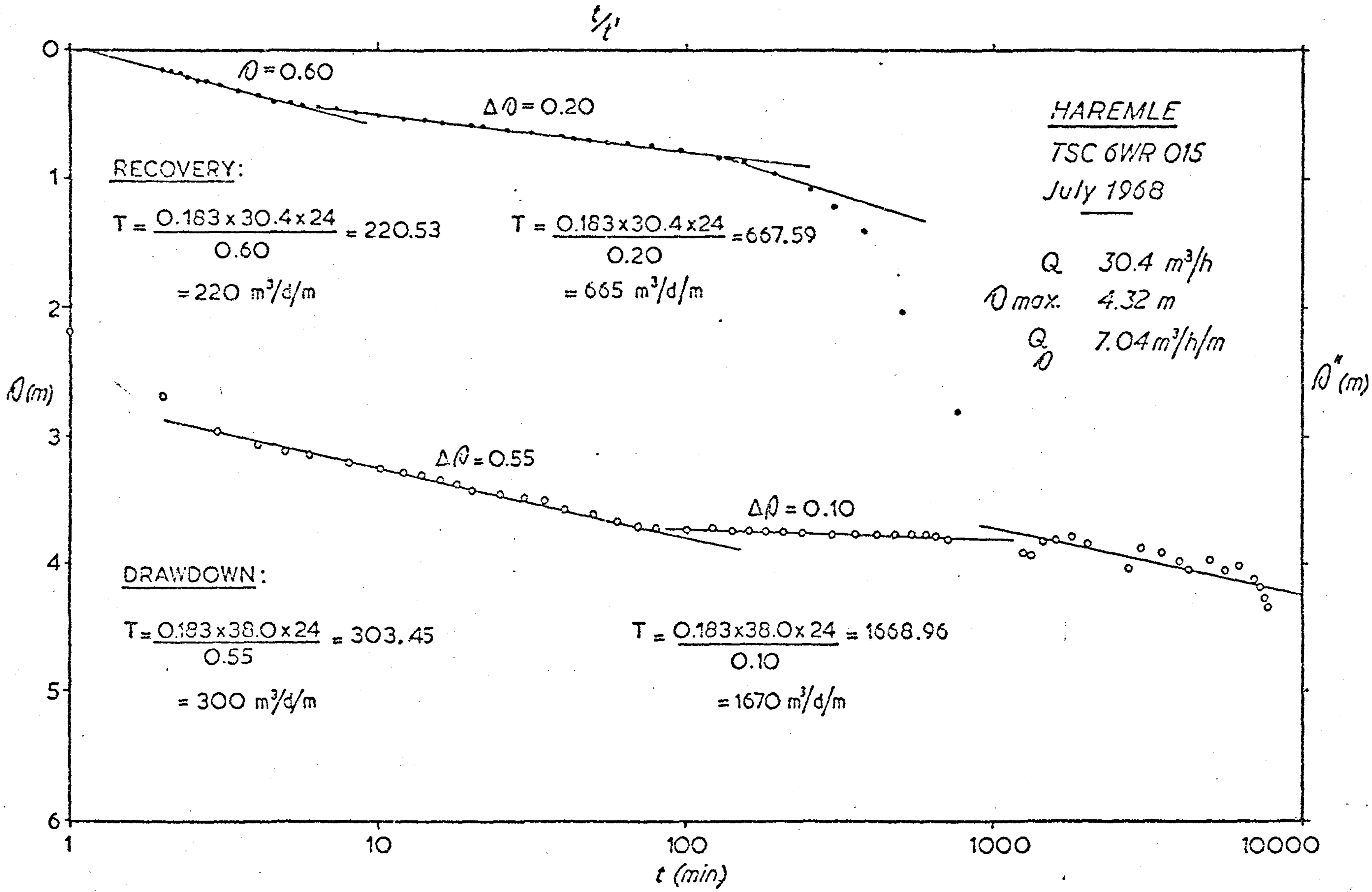


Fig. 6.7 Drawdown and recovery data plot for Well 6WR-015

Drilling and test data are available from the Trans Iran Waterwell Drilling Co., for two wells put down near Khatt on behalf of the Federal Ministry of Electricity and Water in May and June 1975. Khatt No.1 was drilled to 193 ft below surface whereas No.2 was taken slightly deeper to 203 ft b.s., though they both had 130 ft of 12 inch diameter bridge-slotted screen in their lower parts. Well construction details were therefore very similar if not identical, and the lithological description of conglomerates passing downwards into 'very hard rock' below 180 ft b.s. is common to both, though only in No.1 is reference made to 'red sticky clay' (Appendix Ib). This latter feature must be a major contributory cause of the marked difference in performance between the two wells that is summarised below:-

	Well No.1	Well No.2
Discharge	6000 Igph	10800 Igph
Drawdown	112 ft	60 ft
Q/s	54 Igph/ft	180 Igph/ft

No samples of the 'very hard rock' in the basal portion of the holes were available for examination so that it would be somewhat speculative to regard this as the underlying limestone, and even more so as a potential water-yielding formation. Nevertheless, the form of both 'drawdown' and 'recovery' data curves has a suggestion of leaky confined conditions. It is to be regretted that no opportunity was taken to use well No.1 or a pre-existing hole as an observation well during the test of pumping well No.2. This restriction to pumping wells has meant that only transmissivity values can be calculated, because in the absence of any knowledge of the effective radius of the well the storativity cannot be determined.

Conventional plots of drawdown versus log time, and 'calculated recovery' versus log time for well No.1 are given in Fig. 6.8 and indicate a marked deviation of the data from the non-leaky confined conditions of pumping or recovery. The slope of the drawdown data points prior to deviation yields a transmissivity value of $75 m^3/d/m$, but because of inadequate data this value cannot be confirmed from the recovery data. Similar plotting of data from the

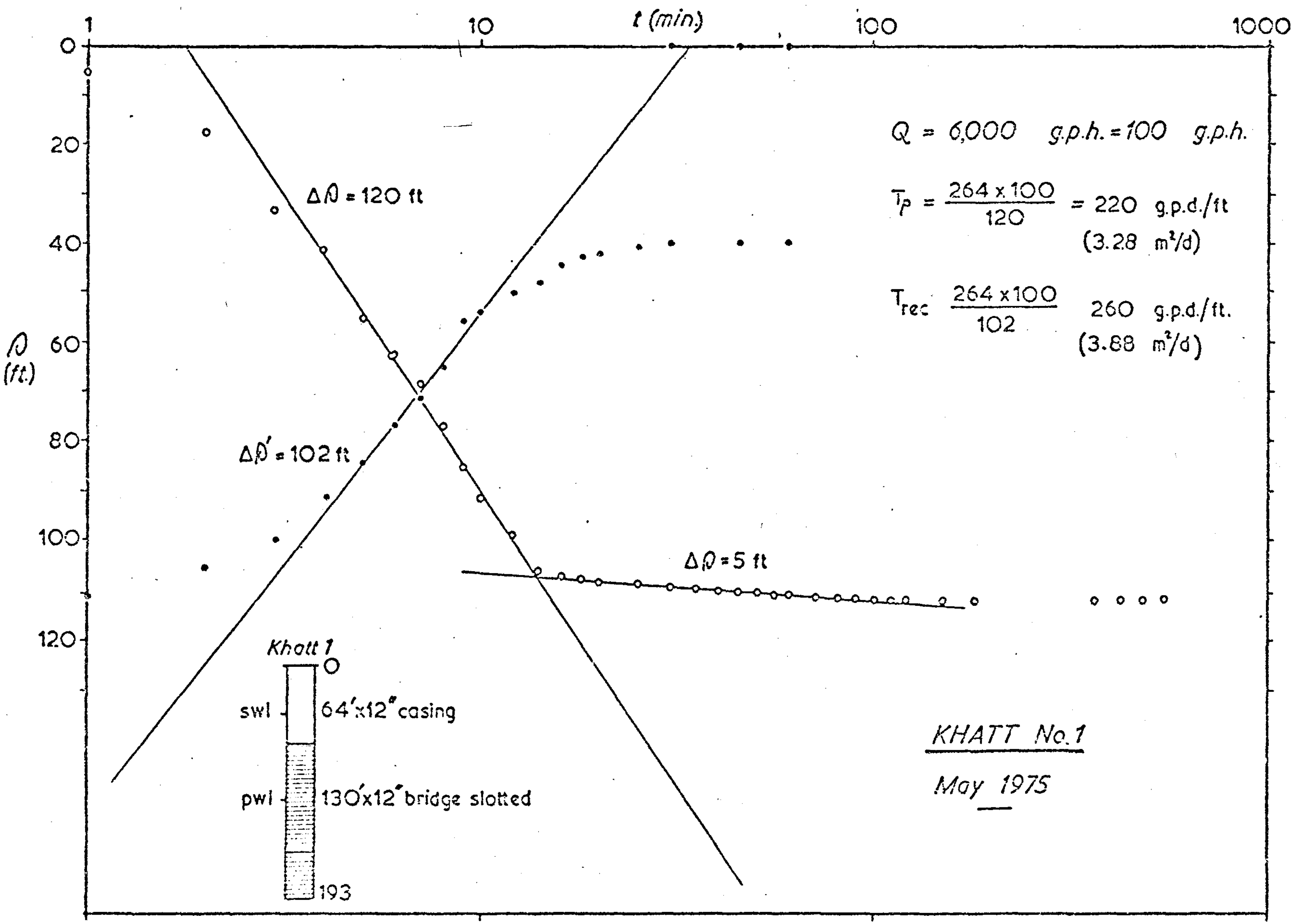


Fig. 6.8 Drawdown and recovery data plot for Well Khatt 1

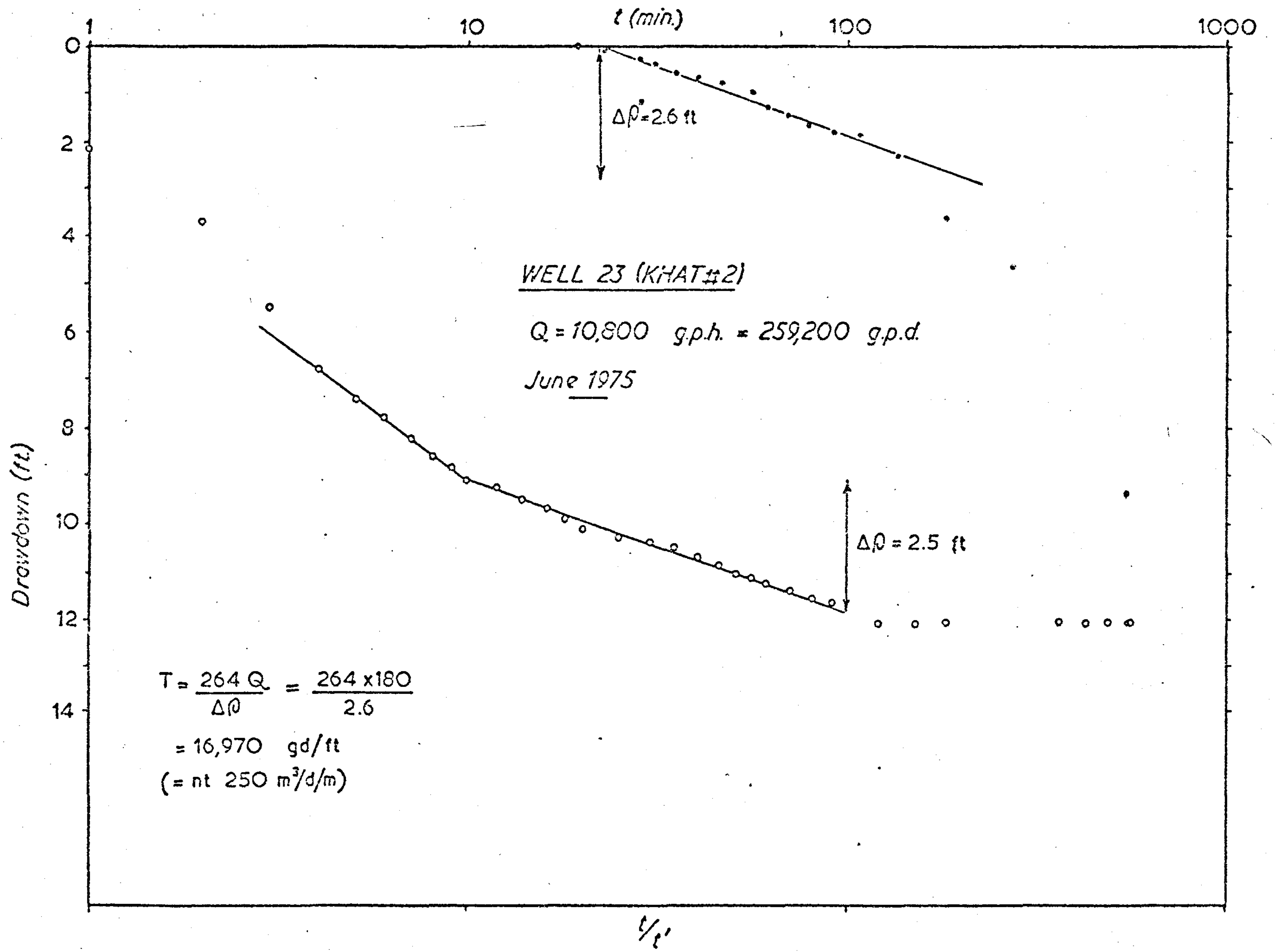


Fig. 6.9 Drawdown and recovery data plot for Well Khatt 2

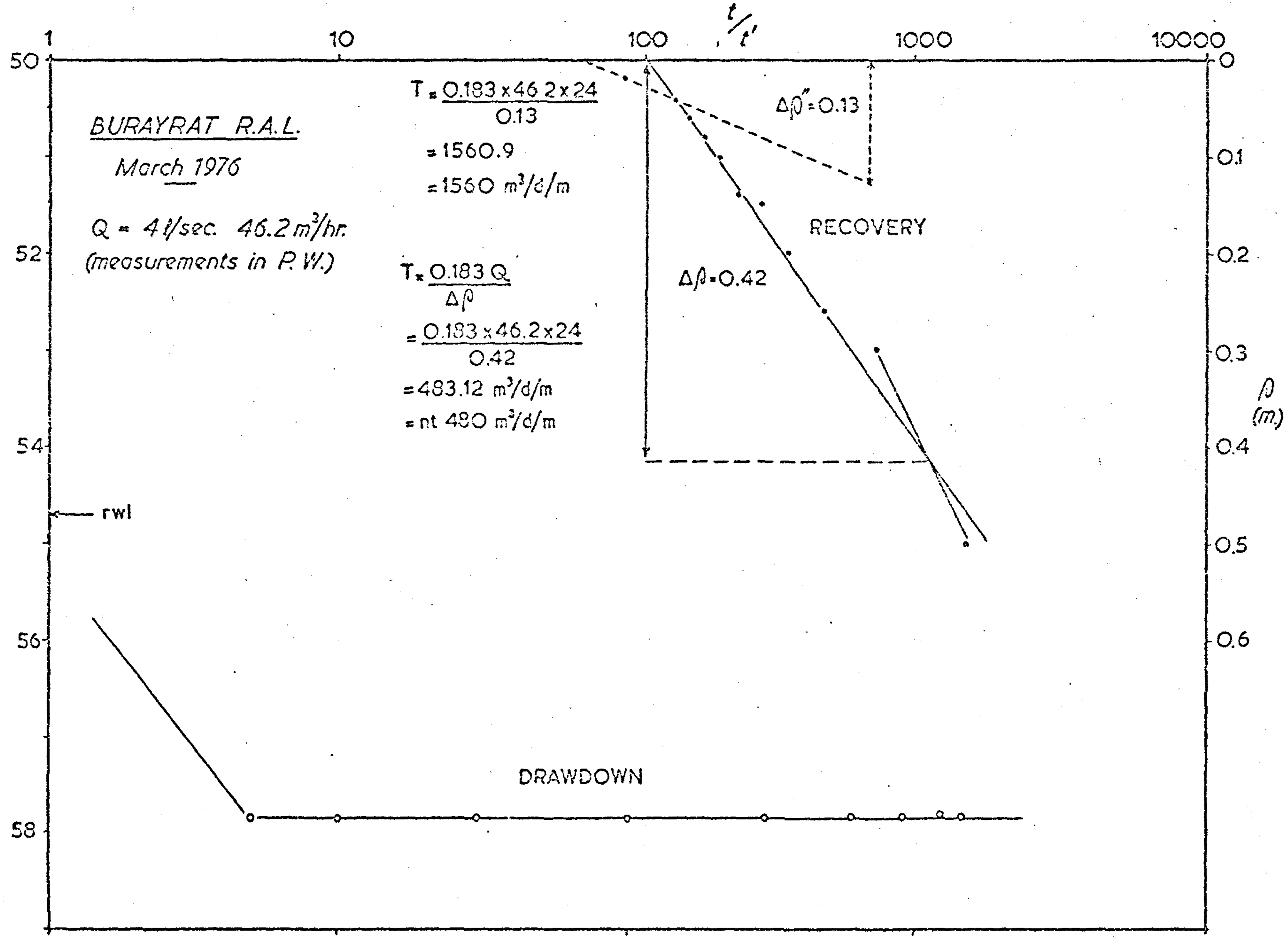


Fig. 6.10 Drawdown and recovery data plot for Burayrat

testing of well No.2 is provided in Fig. 6.9 with a calculated value for transmissivity from both drawdown and recovery data equivalent to about 250 m^3/d/m. There is no obvious explanation for such a marked difference in sites so close together unless one considers it to be the effect of the clays reported from well No.1. More recently (March 1976) the Lebanese firm of Dar Al Handasah tested a new well drilled by IWWD for the RAK Government at Burairat and again using recovery data, calculated the transmissivity to be 507 m^3/d/m. The basic field data from this test were available and the drawdown and recovery data were re-plotted as in Figure 6.10. The drawdown data may be seen to be extremely limited, with a rest water level of 54·70 m below measuring point drawn down without intermediate measurement to 57·86 m within the first five minutes of pumping at a rate of 46·2 m^3/hour, and with occasional fluctuations of 1 cm, remained at that level for the duration of the 24 hour test pumping. The only use that can be made of these drawdown data is to calculate the apparent specific capacity of the well (Q/s) as 14·62 m^3/h/m. The recovery data are more amenable to analysis, though it should be noted that since full recovery was apparently achieved in 20 minutes there is a somewhat restricted spread of data points. The calculated value of transmissivity is about 480 m^3/s/m which is comparable with the previously determined value. It should be noted, however, that reliance has been placed on data points other than the last few. If the latter had been sufficiently numerous some confirmation might have been forthcoming for the alternative calculated value of 1560 m^3/d/m.

Fortunately, during 1977 the Electricity and Water Department of the Government of Ras Al Khaimah agreed to finance the testing of wells at sites of potential large-scale abstraction near Burairat, Sha'am and Sayh al Fayhlayn. The test at Burairat was terminated due to operational difficulties but full scale tests were completed at the other two sites and are treated here in detail because they provide important procedures and analytical solutions that are

WADI SHA'M WATER WELL FIELD

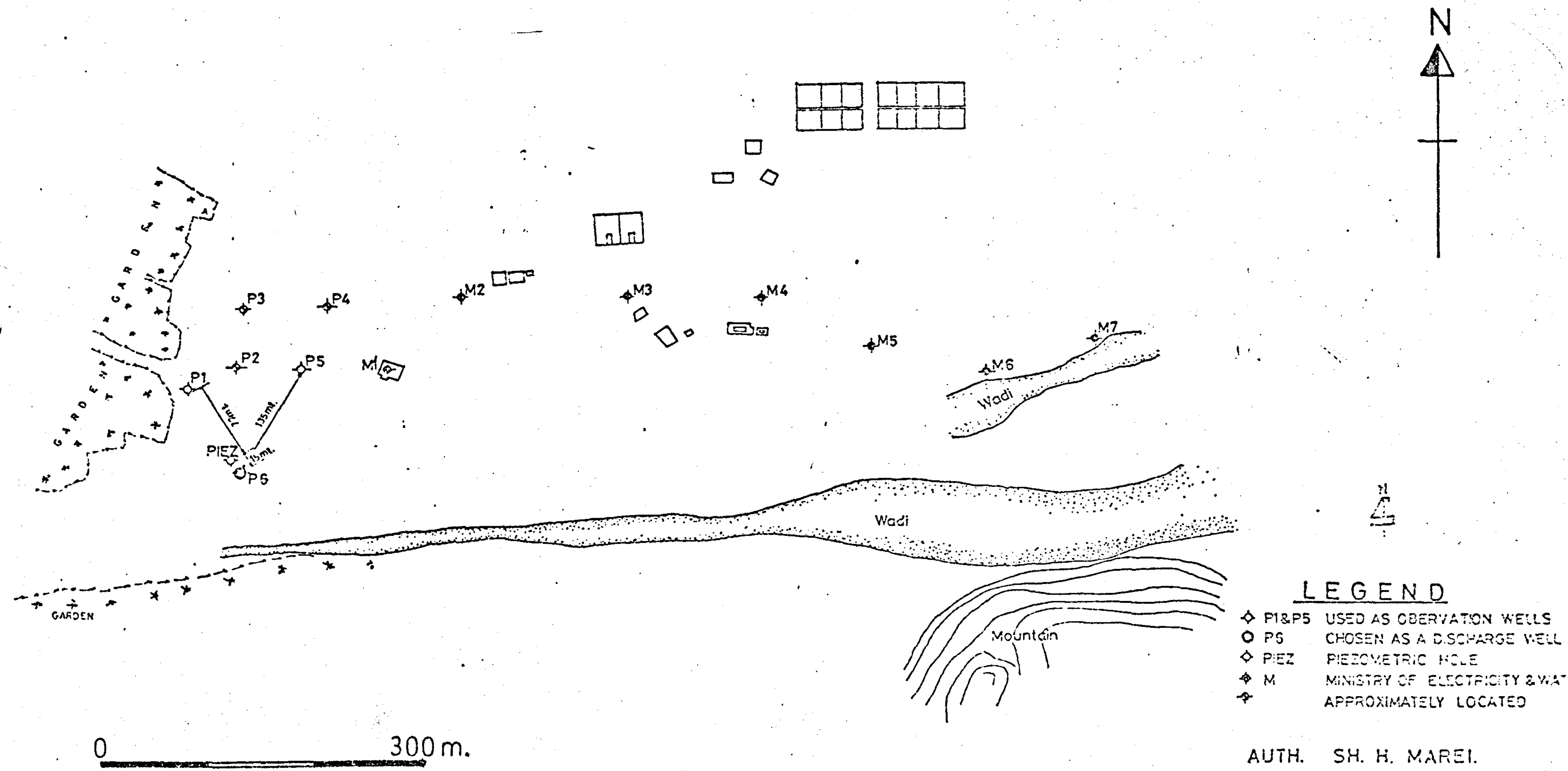


Fig. 6.11 Test layout at Sha'am

new to the study area. In both cases an existing production well was adopted as the pumping well and other production wells likewise served as observation points. Additionally, in order to provide drawdown measurements close to the pumping well an observation well $9\frac{5}{8}$ inch in diameter was drilled to a depth comparable with that of the pumping well, fitted with 3 inch diameter PVC casing and screen with gravel envelope and developed by intermittent pumping for a period of 5 hours. The standard pumping test consisted of two parts, firstly a step-drawdown test at three increasing stages of discharge, and secondly, a constant rate test with collection of drawdown and recovery data. The work was undertaken by International Water Well Drilling Co. (IWWD) according to their standard test procedure, and the results were submitted to Dar al Hamdasah, the consultants acting for the Government.

Sha'am: The test layout is shown in Figure 6.11 and illustrated in Photos 6.9 to 6.14 which draw attention to some of the significant features. The basic test data are included in Appendix I(c).

DAH Consultants submitted a report in June 1977 which included an analysis of the test data. It contained a number of anomalies and some considerable misinterpretations, and their results are summarised below:-

Well number	r (m)	Drawdown T (m^2/d)	Drawdown S (-)	Recovery T (m^2/d)
P7	-	-	-	13,219
O1	15	45,533	$3{\cdot}16\times10^{-1}$	10,108
P1	92	1,028	$0{\cdot}54\times10^{-3}$	15,206
P5	138	5,616	$2{\cdot}77\times10^{-3}$	-
average values: T = 15,118 m^2/d			S = $1{\cdot}06\times10^{-1}$	

Again reliance has been placed on the straight-line method without appreciating that the prevailing water table conditions should produce three segments in the data plots for both drawdown and recovery, as has previously been described. Since these calculations are based upon a false premise,

Photo. 6.9: View of test locality at Sha'am.

Photo. 6.10: Pumping well with control valve and access for measuring line at Sha'am.

Photo. 6.11: Discharge water carried in pipeline away from pumping well for disposal at Sha'am.

Photo. 6.12: Discharge water gauged in weir box with baffle and 'V' notch.

Photo. 6.13: Existing production well used as observation point at Sha'am.

Photo. 6.14: Specially drilled observation point at 15 m from pumping well at Sha'am.

they produce results that may be seen to vary widely from 1028 m^2/d to 45,533 m^2/d, with the accepted average of the six determinations being 15,118 m^2/d. It is surprising that such suspiciously high values were not highlighted since the maximum value is equivalent in English units to more than 3 million Igpd/ft, while the average value is equal to 1 million Igpd/ft. These results are clearly quite erroneous and would be particularly misleading to anyone using such information for predictive purposes.

Re-analysis of the data is shown in Figure 6.12 from which it is possible to appreciate how the erroneous results were derived. The data are not of the text book variety, and are largely dependent on the results from the newly drilled observation well which produced drawdown values that were more amenable to analysis than those from wells at greater distance. One complication that might have been anticipated was the failure to ensure that pumping in adjacent private wells did not take place during the test period. In this connection, and remembering that time is plotted on a logarithmic scale, the interruption was longer than might appear from a casual inspection of the plot.

With foreknowledge of the water table conditions from the available hydrogeological information one may presume that most of segment 1 in the observation well at 15 m distance was missed by delaying measurement until two minutes after the start of pumping. Segments 2 and 3 are distinct, however, and the additional effects of the pumping of the two private wells was less marked than in those observation wells closer to such pumping. The calculations for transmissivity and storativity are as follows:-

$$T = \frac{0{\cdot}183 \times 104 \times 24}{0{\cdot}15} = 3045 \quad m^3/d/m$$

$$S = \frac{2{\cdot}25 \times 3045 \times 1{\cdot}6}{(15)^2 \times 1440} = 0{\cdot}034$$

Observation wells P-1 and P-5 at 92 m and 138 m respectively from the pumping well have a stepped pattern from which it may be inferred not that the dis-

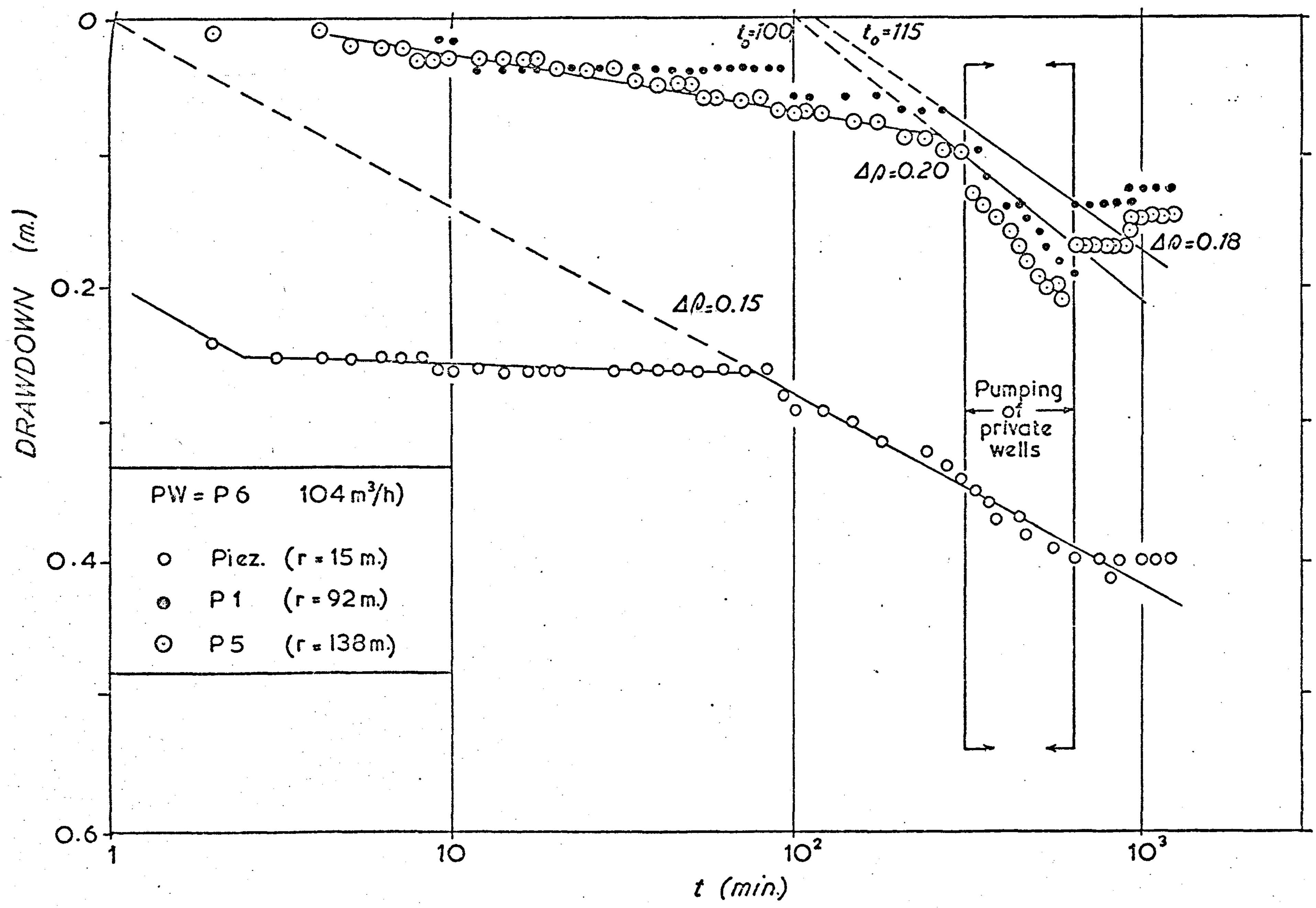


Fig. 6.12 Drawdown data plots for three observation wells at Sha'am.

charge varied in this way, but simply that measurements were made to the nearest centimetre. With P-1 being the closer of the two to the main pumping well it is possible to identify various segments if the first reading is ignored as drawn in Figure 6.12. It is fortunate that the change to segment 3 occurred sufficiently long before the start of private pumping for some determination to be made of its slope with resultant calculation of the hydraulic propérties as follows:

$$T = \frac{0{\cdot}183 \times 104 \times 24}{0{\cdot}20} = 2283 \text{ m}^3/\text{d/m}$$

$$S = \frac{2{\cdot}25 \times 2283 \times 100}{(92)^2 \times 1440} = 0{\cdot}042$$

In the case of observation well P-5 the private well pumping interfered with water levels before the third segment was attained and the necessary extrapolation to the later data must make the following calculations of T and S estimates rather than determinations:-

$$T = \frac{0{\cdot}183 \times 104 \times 24}{0{\cdot}18} = 2538 \text{ m}^3/\text{d/m}$$

$$S = \frac{2{\cdot}25 \times 2538 \times 115}{(138)^2 \times 1440} = 0{\cdot}024$$

In conclusion, the reinterpretation of the Sha'am test results point to a transmissivity value ranging between 2000 and 3000 m^2/d, with a storativity in the range of 0·02 to 0·04 which are more acceptable than those quoted previously.

Sayh al Fayhlayn: The location of the site and the test layout are shown in Figure 6.13 and illustrated in Photos 6.15 to 6.20, with the test data included in Appendix I(d). A constant-rate test for a duration of 21 hours was conducted with existing production well G-5 as the pumping well. Due to difficulties in locating the water level below 29 m in the pumped well, the discharge was reduced after one hour from 86 m^3/h to 71·6 m^3/h with resultant difficulties in data analysis. It would have been preferable to have stopped

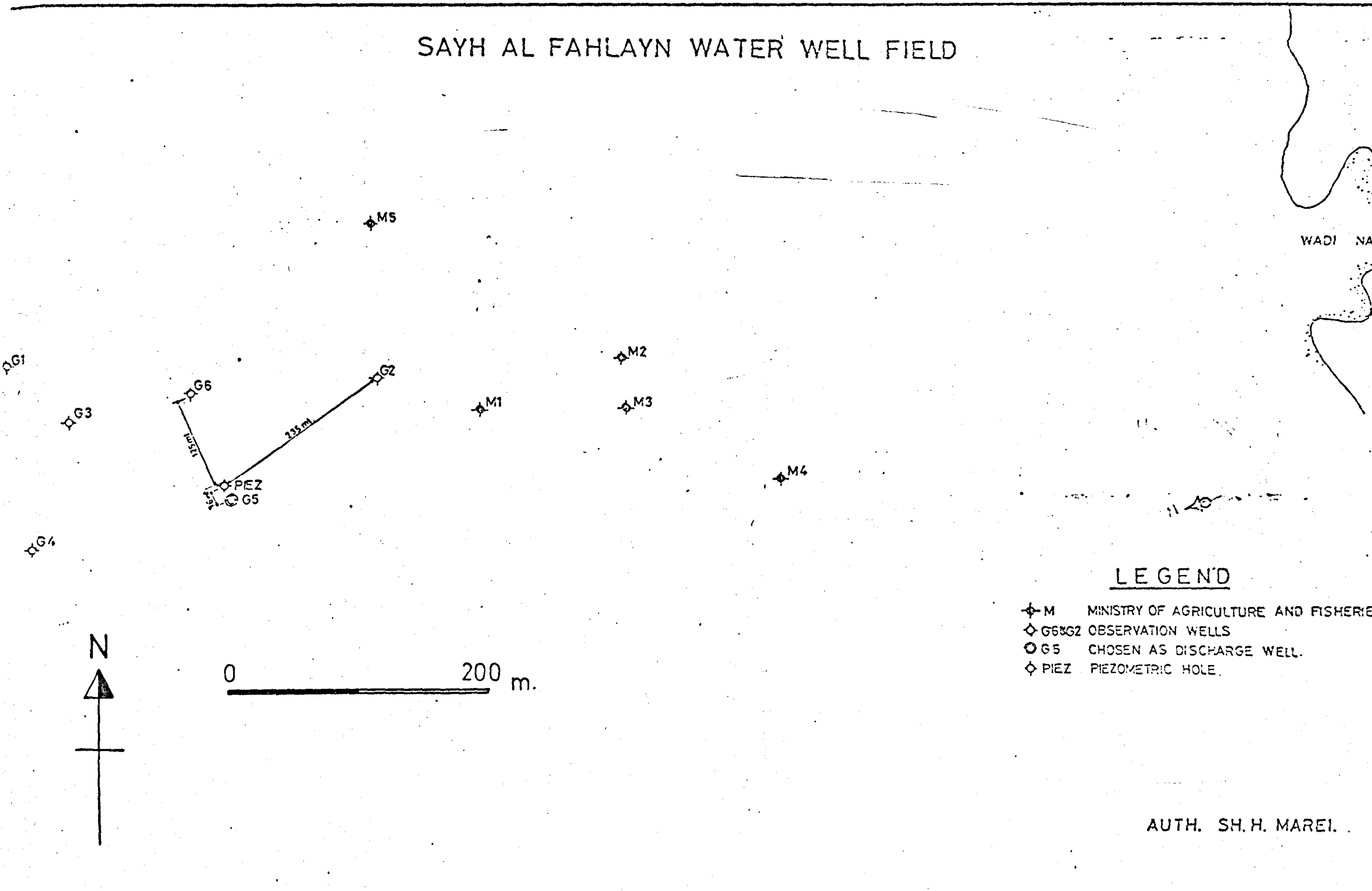


Fig. 6.13 Test layout at Sayh al Fahlayn

Photo. 6.15: Prospective well field area on gravel plain at Sayh al Fahlayn.

Photo. 6.16: View of test locality at Sayh al Fahlayn.

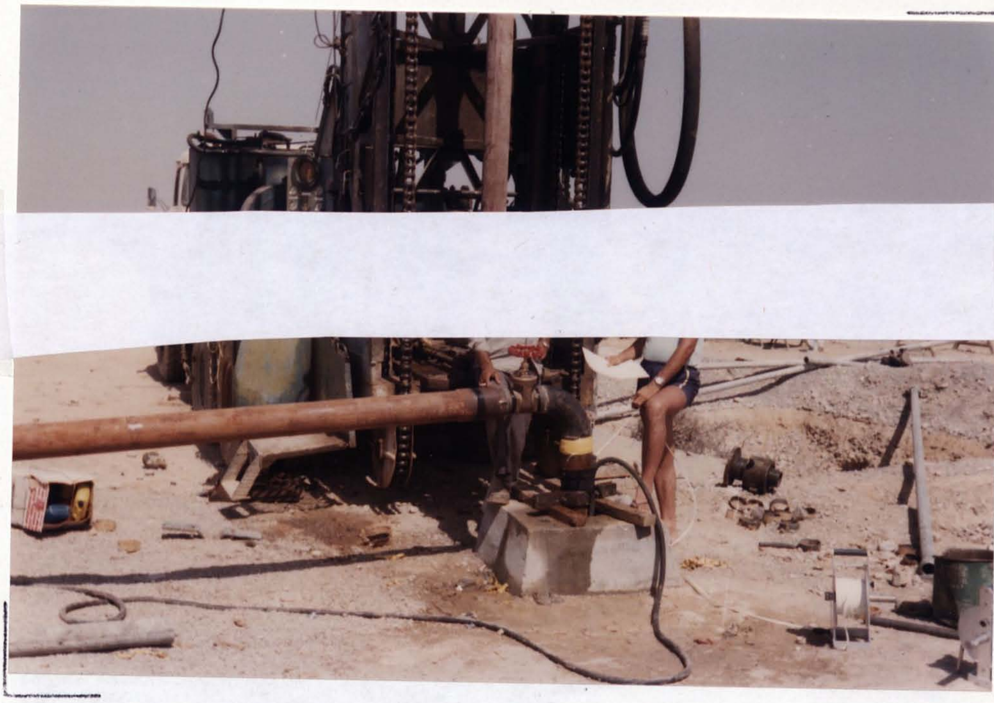


Photo. 6.17: Headworks on pumping well at Sayh al Fahlayn.

Photo. 6.18: Lengthy pipeline for safe disposal of discharge water at Sayh al Fahlayn.

Photo. 6.19: Existing production well used as observation point at Sayh al Falayn.

Photo. 6.20: Specially drilled observation point at 16 m from pumping well at Sayh al Fahlayn.

pumping and to have started again at the lower rate after full recovery had been attained. Three observation wells (O-1, G-6 and G-2) were located at distances 16 m, 141 m and 235 m respectively from the pumping well, the first (O-1) being specially drilled for the purpose while the other two were existing production wells. At no time during the test did water levels in the furthest well ($r = 235$ m) respond to any changes in the pumping well regime. Data were therefore limited to the pumped well and the other two observation wells, and the drawdown results are plotted in Figure 6.14. The recognition of distinct segments is complicated by the change in pumping rate but possible if one concentrates attention on the data related to the lesser discharge rate. In O-1 at 16 m distance using the latest data one can calculate the aquifer properties to be:-

$$T = \frac{0{\cdot}183 \times 71{\cdot}6 \times 24}{0{\cdot}195} = 1613 \text{ m}^3/\text{d/m}$$

$$S = \frac{2{\cdot}25 \times 1613 \times 0{\cdot}64}{(16)^2 \times 1440} = 6{\cdot}30 \times 10^{-3}$$

For observation well G-6 at 141 m distance, the stepped nature of the data make analysis very difficult, but if the interpretation that the late data correspond to segment 3 is correct then the properties are calculated as follows:-

$$T = \frac{0{\cdot}183 \times 71{\cdot}6 \times 24}{0{\cdot}18} = 1747 \text{ m}^3/\text{d/m}$$

$$S = \frac{2{\cdot}25 \times 1747 \times 520}{(141)^2 \times 1440} = 7{\cdot}14 \times 10^{-2}$$

The drawdown data from the pumping well is even more complex but using the latest data provides:-

$$T = \frac{0{\cdot}183 \times 71{\cdot}6 \times 24}{0{\cdot}7} = 449 \text{ m}^3/\text{d/m}$$

This value of transmissivity is anomalously low, and for confirmation, analysis was also made of the recovery data as plotted in Figure 6.15. Values of T calculated from the late recovery data for pumping well G-5 and observation well O-1 were 1250 m^2/d and 1380 m^2/d respectively. Because the time axis

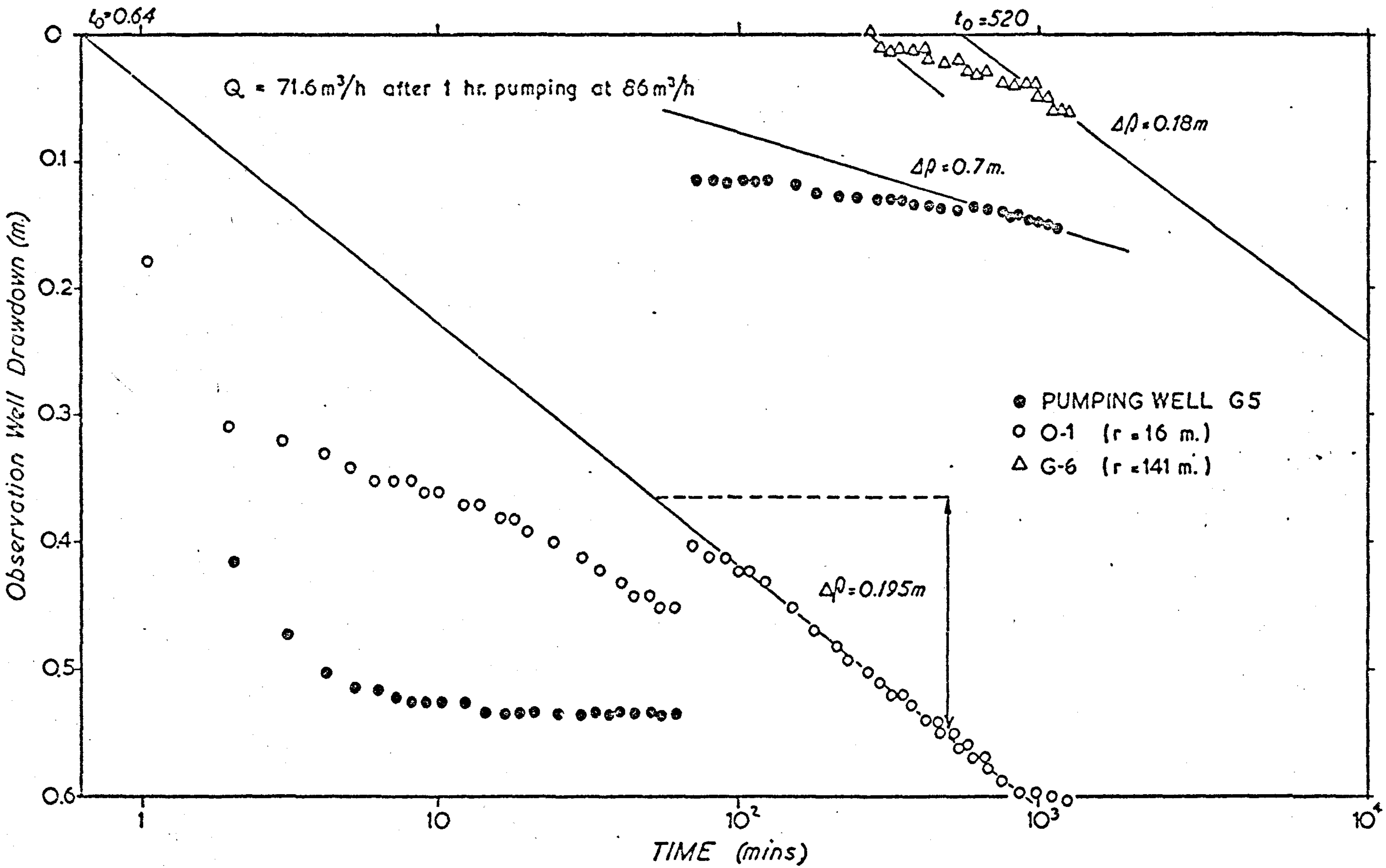


Fig. 6.14 Drawdown data plots for wells at Sayh al Fahlayn

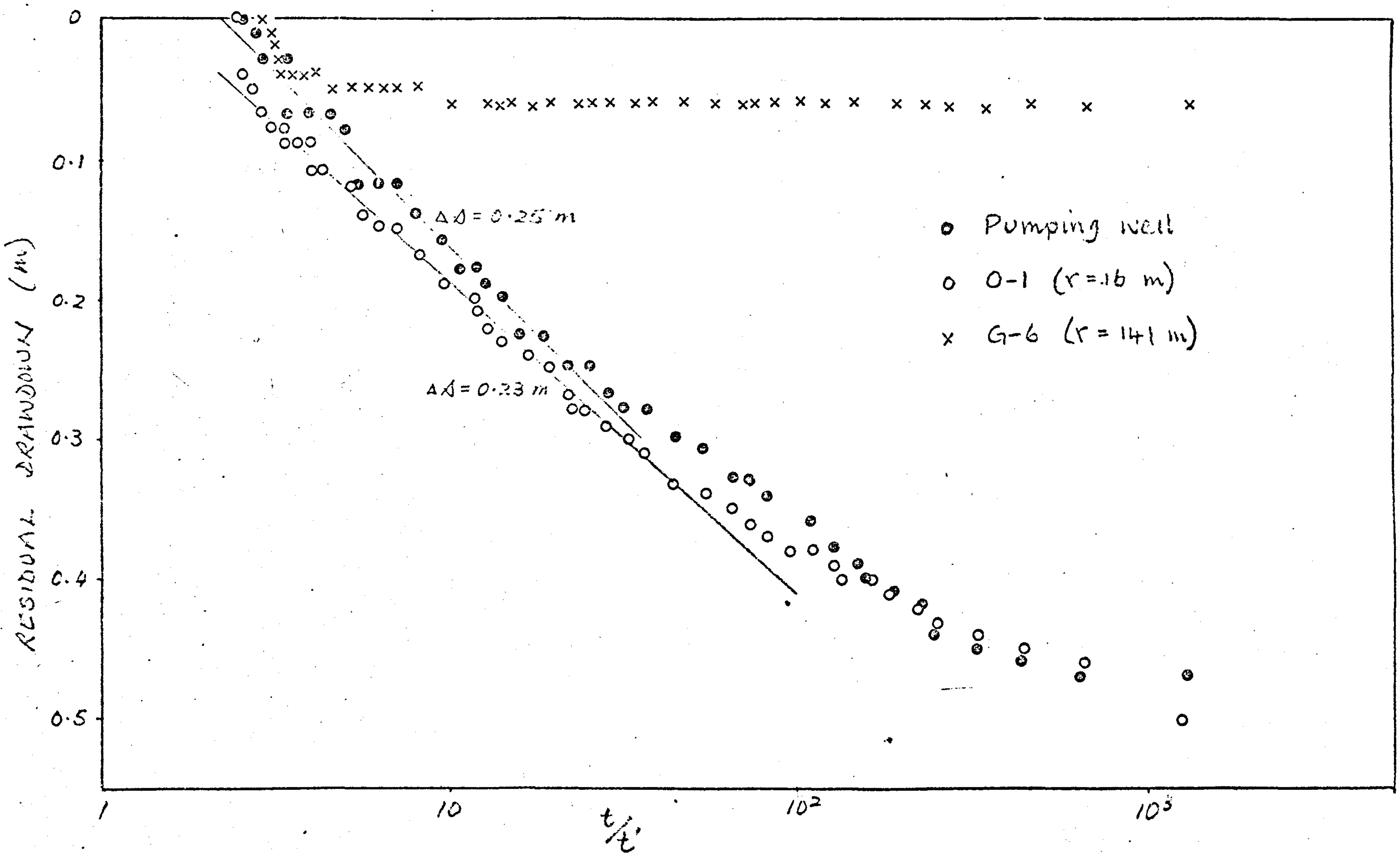


Fig. 6.15 Recovery data plots for wells at Sayh al Fahlayn

for the residual drawdown recovery method solution is a ratio (t/t'), it is not possible to solve for storativity (S). However, when the position of the interception of the straight line with zero residual is not at the point of origin one can make some subjective interpretation of storativity (Johnson, 1972). For example, a value of t/t' = 2 or more as in the test data suggests that some recharge water reached the aquifer during the pumping period, and so produced full recovery in a shorter period of time than expected.

The following tabulation gives a summary of the transmissivity results (in m^2/d) derived by DAH and from this reinterpretation:-

Well	DAH		reinterpretation	
No.	drawdown	recovery	drawdown	recovery
PW	1158	1348	449	1250
"		1244		
0-1	4717	2877	1613	1380
"		1460		
G-6	3568	6566	1747	N.A.

Again, the revised results are lower than those of DAH for reasons similar to those previously described. A reasonable value for transmissivity for Sayh al Fayhlayn would seem to be 1500 m^2/d, and the reasons for the anomalously low value determined from the drawdown phase of the pumping are considered in the section on Well Performance.

Prior to the 1977 test programme the only aquifer testing using observation wells had been undertaken by Sir M. Macdonald and Partners (MMP) in 1971 in connection with an irrigation project at Hamraniyah. For three test sites with individual observation wells the results for transmissivity were 2100, 1000, and 1200 m^2/d, while storativity was 0·10. Figures 6.16 and 6.17 reproduce the data from two of the sites, and give some indication of the difficulty in matching the typical stepped data to the water-table type curves of Boulton (1963).

BOULTON METHOD FOR CALCULATION OF AQUIFER CONSTANTS—TW1

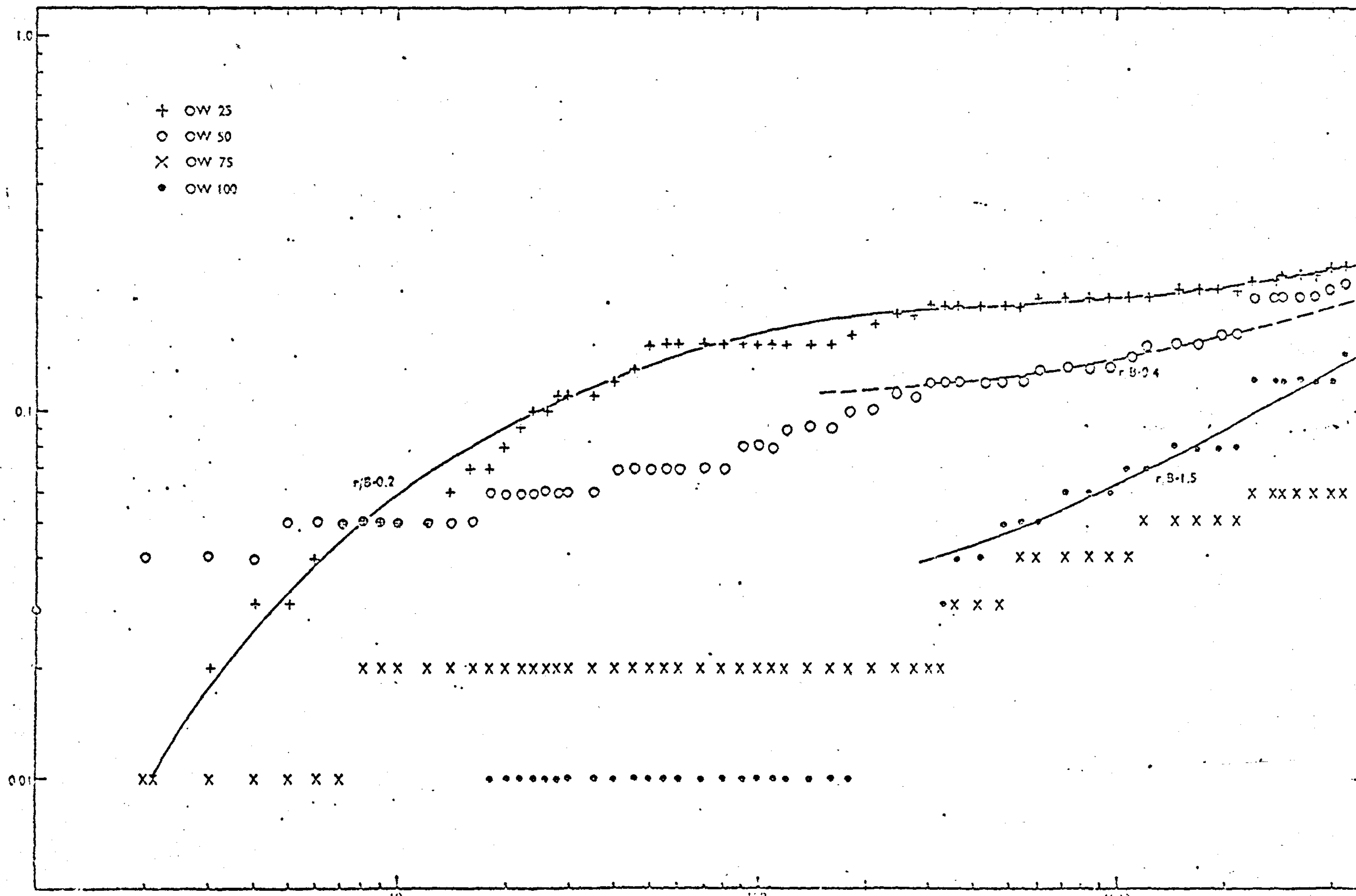


Fig. 6.16 Drawdown data plot for wells TW-1 at Hamraniyah

BOULTON METHOD FOR CALCULATION OF AQUIFER CONSTANTS—TW3

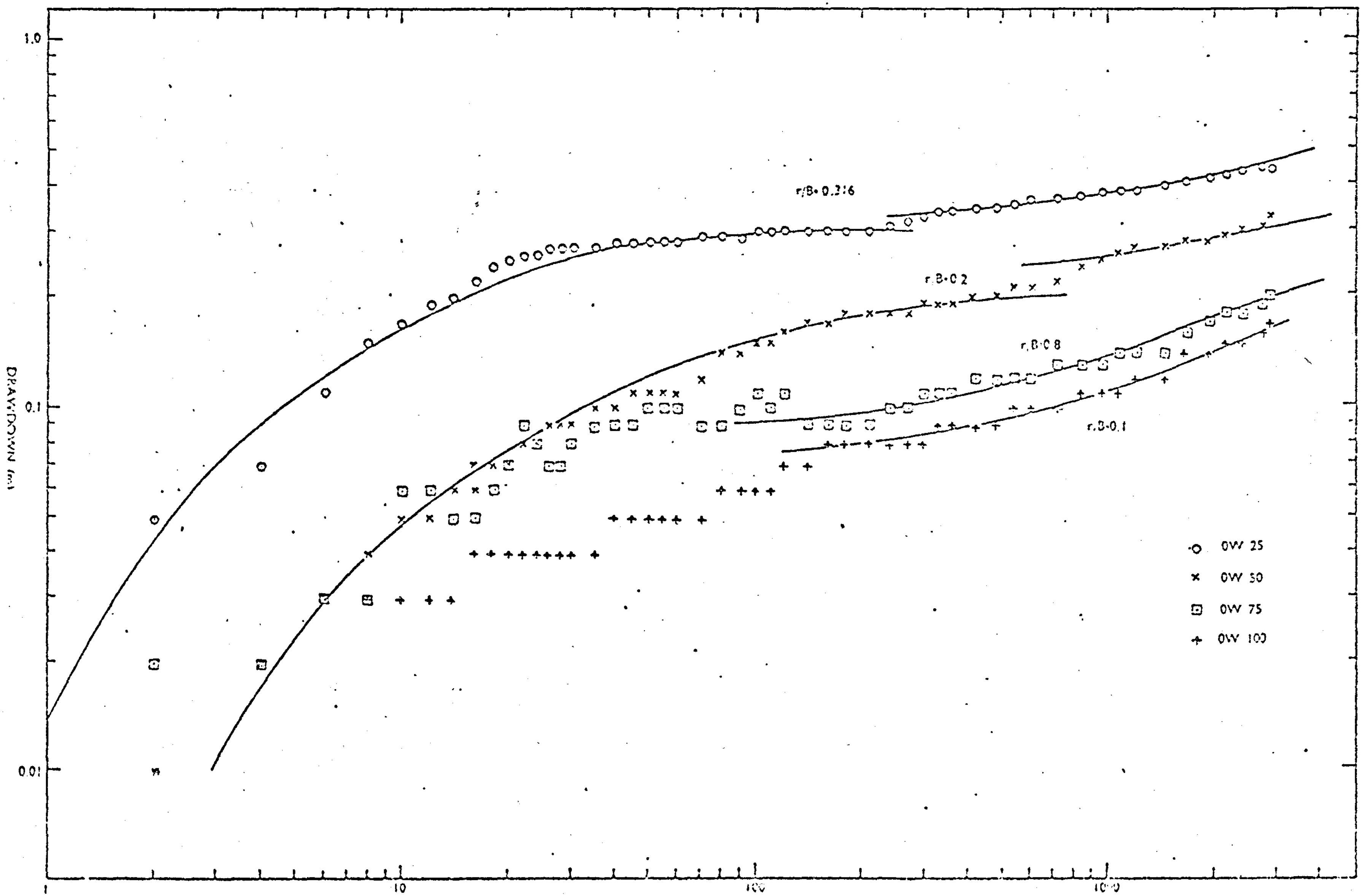


Fig. 6.17 Drawdown data plot for wells TW-3 at Hamraniyah

Values for transmissivity from the Dhaid area in the southern part of the gravel plain range from 10 to 150 m^2/d (HTS, 1975). The distinctly lower values are regarded as being due to the conglomerate aquifer having a mud-flow origin with overall low permeability except for occasional lenses of well-sorted gravel which supply the bulk of the water supply.

6.4 WELL PERFORMANCE

Given the variable nature of the aquifer, it is not surprising that the yields from the boreholes show wide variation. For example, in the SWH Water Resources Survey (1969) well yields ranged from less than 1 m^3/h to 81·8 m^3/h, with an average yield of over 28·3 m^3/h. In the more recent boreholes put down in the area by IWWD, the yields range from 30 m^3/h to over 90 m^3/h. This variation in yield undoubtedly reflects differences in permeability in many cases, but sometimes may be due to limitations on the size of pump used for abstraction. From a users viewpoint, some water is better than none at all, but every effort should be made to obtain the optimum performance from each well.

A useful measure in this respect is the specific capacity (Q/s) which expresses the performance of a well in terms of yield per unit drawdown. It is determined by dividing the discharge by the maximum drawdown after a particular duration of pumping. The SWH results for specific capacity range from 1 $m^3/h/m$ to over 2500 $m^3/h/m$, while those from IWWD show less variation in ranging from 200 to 1000 $m^3/h/m$. In using specific capacity determinations to compare two or more wells, it is necessary that they should have similar diameters, lining construction, and saturated thickness of aquifer.

This simple measure of performance can also be used to estimate the transmissivity of that part of the aquifer in the vicinity of the pumping wells by use of the following equation, the terms of which have been defined previously:-

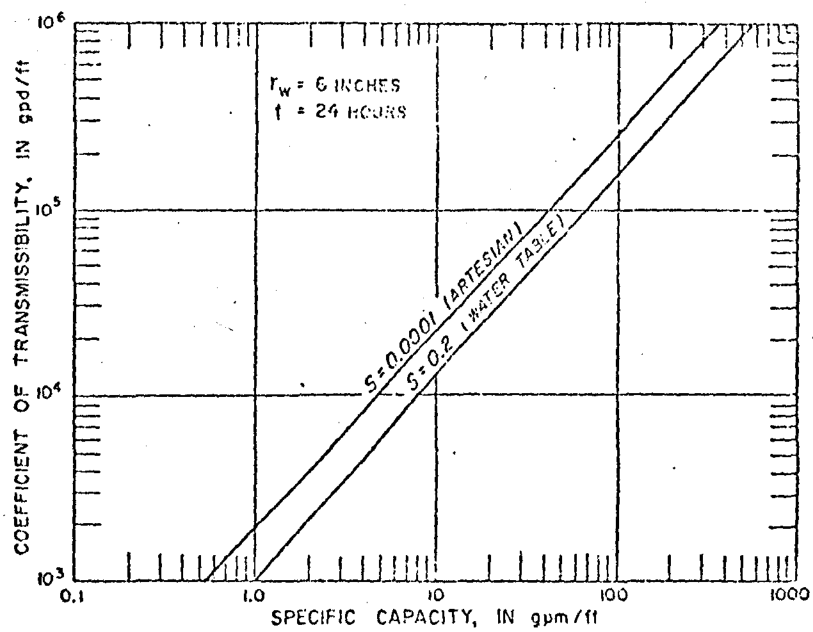


Fig. 6.18 Graph showing $^Q/_s$ versus T (from Walton, 1970).

$$\frac{Q}{s} = \frac{T}{0{\cdot}183 \log \left(\frac{2{\cdot}25\ Tt}{r_w^2\ S}\right)}$$

Because the T term is unknown and appears both as the numerator and as part of the denominator, it is necessary to resort to the preparation of such diagrams as Figure 6.18 (Walton, 1970) for a rough estimate of transmissivity. Estimates of T from specific capacity data in the study area have an upper limit of 1500 m^2/d and are thereforelower than those determined by the more conventional methods. It will also be remembered from the previous section that calculation of T at Sayh al Fahlayn from drawdown and recovery data gave 449 m^2/d and 1250 m^2/d respectively.

One possible explanation for the lower than expected transmissivity values is that the measured drawdown may be detrimentally affected by well losses, and it was decided to incorporate some step-drawdown testing in the programme so as to check on the magnitude of such losses.

The total drawdown in a pumped well is dependent partly on the transmissivity of the aquifer and partly on the construction and efficiency of the well. The head losses due to these two components are known as aquifer loss and well loss respectively, and can be expressed as the equation:-

$$s_t = s_a + s_w$$

where s_t = total drawdown in pumped well

s_a = aquifer loss; that part of drawdown due to laminar flow in the aquifer

s_w = well loss; that part of drawdown due to non-laminar flow in and near the well

Some degree of aquifer loss is inevitable, while good well design, construction and development can minimise well loss. In a 100 percent hydraulically efficient pumping well there is no well loss so that $s_t = s_a$, though this is a theoretical ideal that is rarely obtainable at practicable abstraction rates.

Jacob (1947) derived the equation $s_t = BQ + CQ^n$ where B and C are the aquifer and well loss constants respectively, Q is the prevailing pumping rate and n is a variable exponent. Dividing through by Q gives the form $s/Q = B + CQ^{n-1}$. On the assumption that for turbulent or non-laminar flow, the losses are related approximately to the square of the discharge, Jacob proposed that n = 2 when the equation becomes that of a straight line. Rorabrough (1953) and Lennox (1966) suggested that n may sometimes be greater than 2 and as high as 3 or greater, in which case the equation becomes that for a parabola. Parameters B and C can be determined graphically by plotting specific drawdown (s/Q) versus Q for different discharges. C is determined from the slope of the line of best fit through the data points, with B being calculated from the intercept of that line with the s/Q axis.

Reliable step-drawdown tests from the study area are lacking for they were not part of the regular SWH test procedure. In their feasibility report on the Hamraniya irrigation project, MMP provided step-drawdown test data and analyses for three sites. The results have been replotted as shown in Figure 6.19 and are instructive in providing typical examples of some of the prevailing conditions. TW-1 has a parabolic nature, TW-2 has an impossible negative slope, while TW-3 provides the only results that can be used for predictive purposes. Whichever method is used, the calculated values of B and C should be checked by solution of the equation $s_t = BQ + CQ^2$ for a known pumping rate and comparison with the measured drawdown from the available test data. Taking TW-3 and adopting values of $B = 3{\cdot}1 \times 10^{-2}$ and $C = 6{\cdot}88 \times 10^{-4}$ with a pumping rate of $46{\cdot}6\ m^3/h$, the equation for $s_t = 1{\cdot}45 + 1{\cdot}49 = 2{\cdot}94$ m which compares favourably with the measured value of 2·88 m. What it also indicates is that at the pumping rate used, half the drawdown is the result of well loss.

The special tests at Sha'am and Sayh al Fahlayn also incorporated a step-drawdown test with results as tabulated below:-

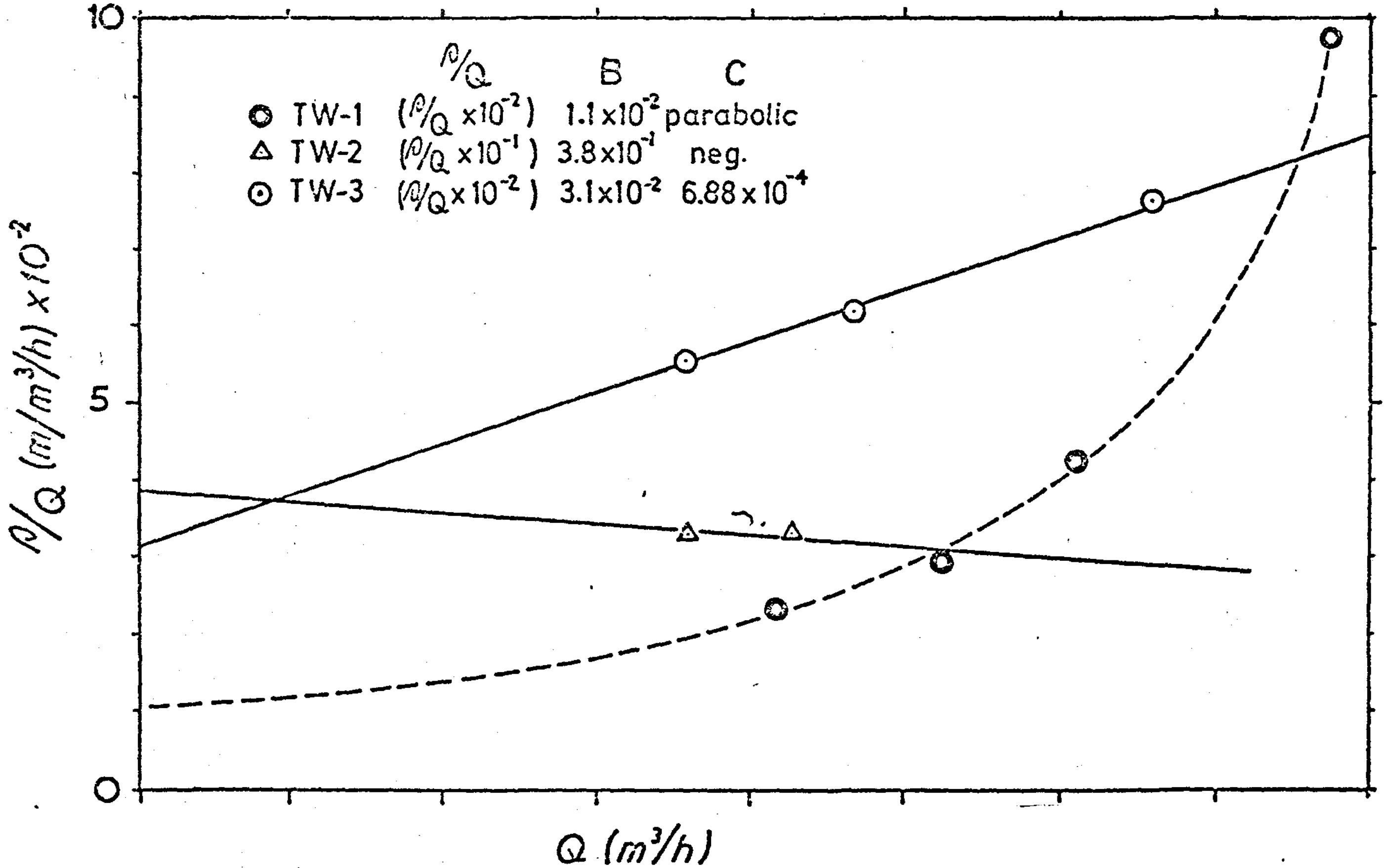
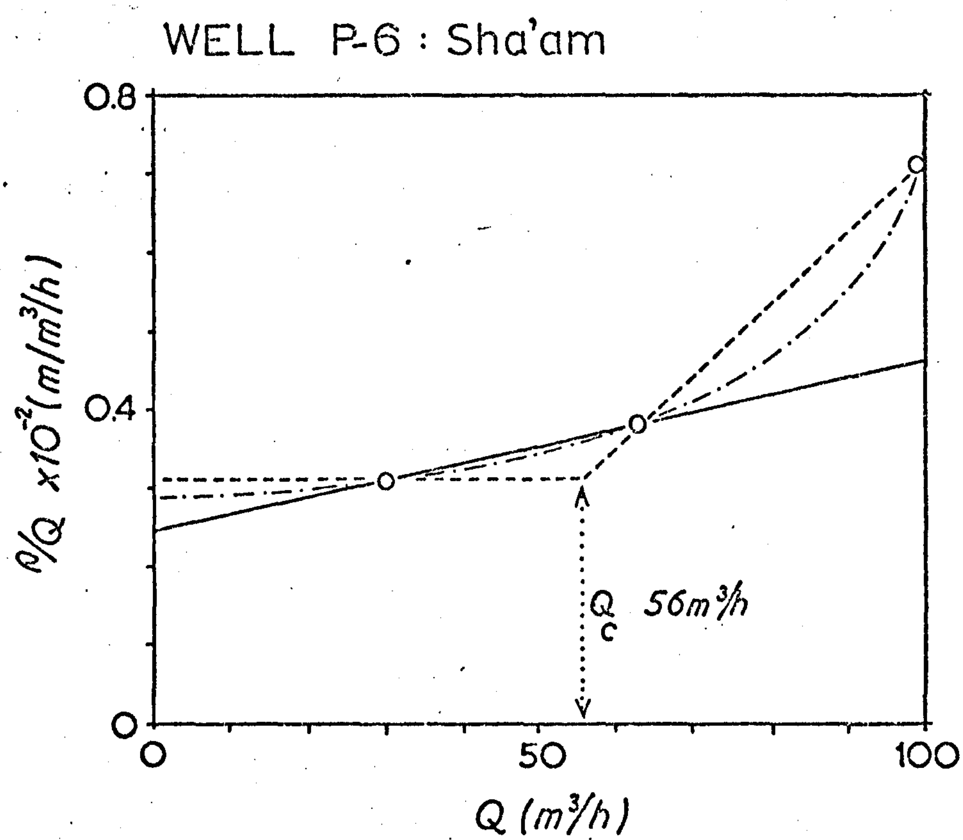


Fig. 6.19 Step-drawdown test results from Hamraniyah

Well No.	Q (m^3/h)	s (m)	s/Q (h/m^2)
Sha'am P-6	30·60	0·97	$3{\cdot}17 \times 10^{-2}$
	62·28	2·39	$3{\cdot}84 \times 10^{-2}$
	99·72	7·17	$7{\cdot}19 \times 10^{-2}$
Sayh al Fahlayn G-5	30·6	0·79	$2{\cdot}58 \times 10^{-2}$
	62·28	3·54	$5{\cdot}68 \times 10^{-2}$
	86·04	4·78	$5{\cdot}56 \times 10^{-2}$

They were analysed as previously, and the graphical representation of the Sha'am data in Figure 6.20(a) is open to a number of alternative interpretations. For example, it could be 1) a positively sloping straight line with n = 2 but anomalous values for the third step, or 2) a parabolic distribution with n > 2, or 3) an initial horizontal distribution indicative of no well loss, with a positively sloping straight line indicative of well loss at values greater than some critical discharge (Q_c). Although a common practice, the restriction to three steps provides insufficient points for meaningful consideration of the above mentioned alternatives, and reliance has been placed upon the Jacob standard method with n = 2. For P-6, the constant $B = 1{\cdot}4 \times 10^{-2} h/m^2$ with $C = 4 \times 10^{-4}\ h^2/m^5$; while for G-5 at Sayh al Fahlayn from a straight line fit through only two data points (Fig.6.20(b)), $B = 1 \times 10^{-2}\ h/m^2$ and $C = 5{\cdot}3 \times 10^{-4}\ h^2/m^5$.

Use of these calculated constants in the equation $s_t = BQ + CQ^2$ to determine the proportion of aquifer and well losses at different discharges is illustrated in Figure 6.21 and shows the relatively rapid increase of well loss. In both Sha'am and Sayh al Fahlayn, any increase in discharge beyond 30 m^3/h produces the situation where the drawdown component due to well loss is greater than that due to aquifer loss. Indeed, it implies that at the lowest rate used in the pumping tests (30·6 m^3/h), both wells were only 50 percent efficient. These indications would be substantiated by more



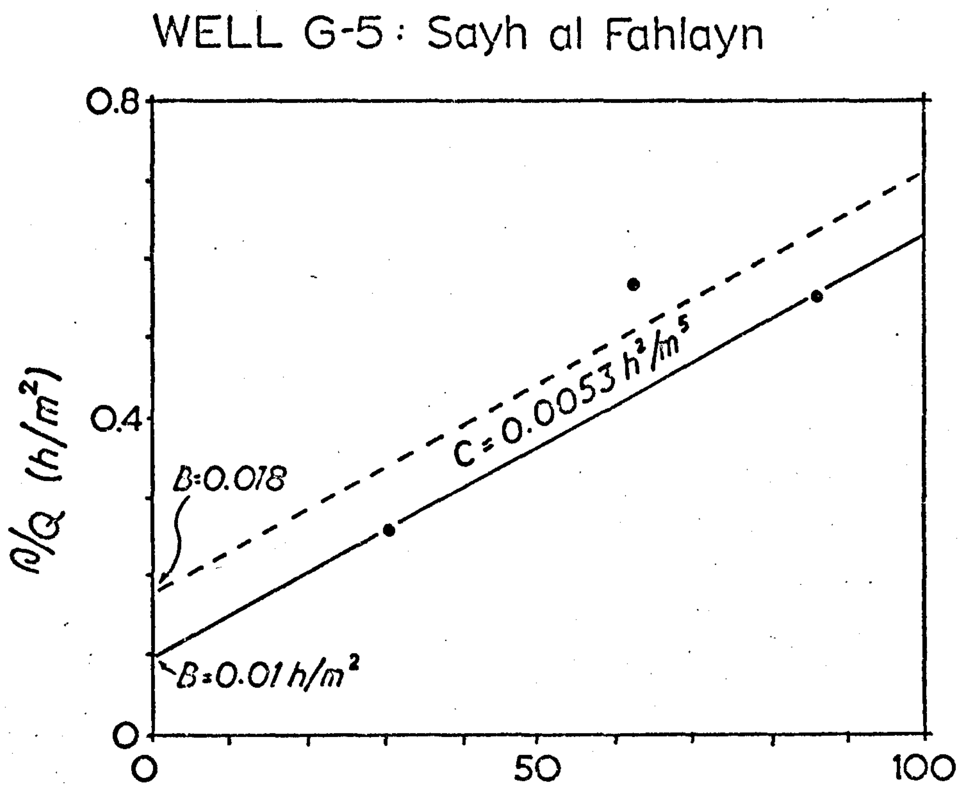
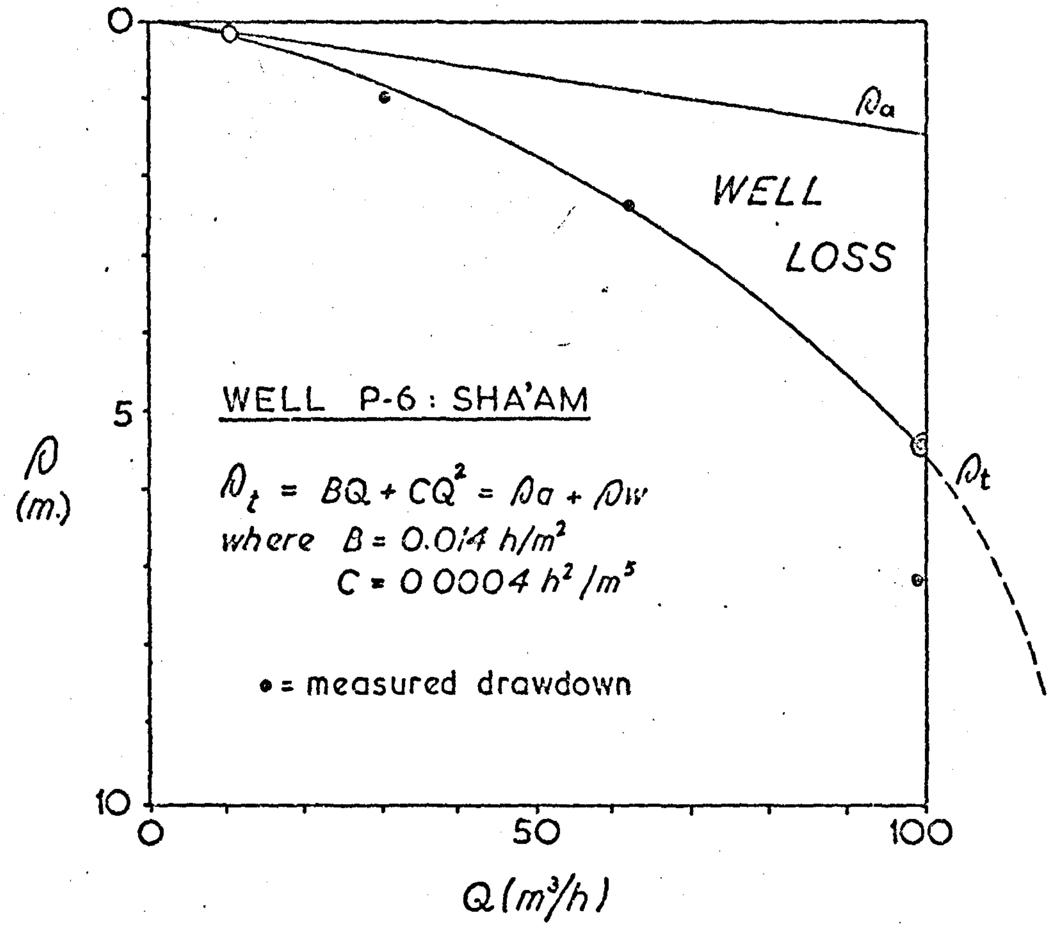


Fig. 6.20 Step-drawdown test results from Sha'am and Sayh al Fahlayn



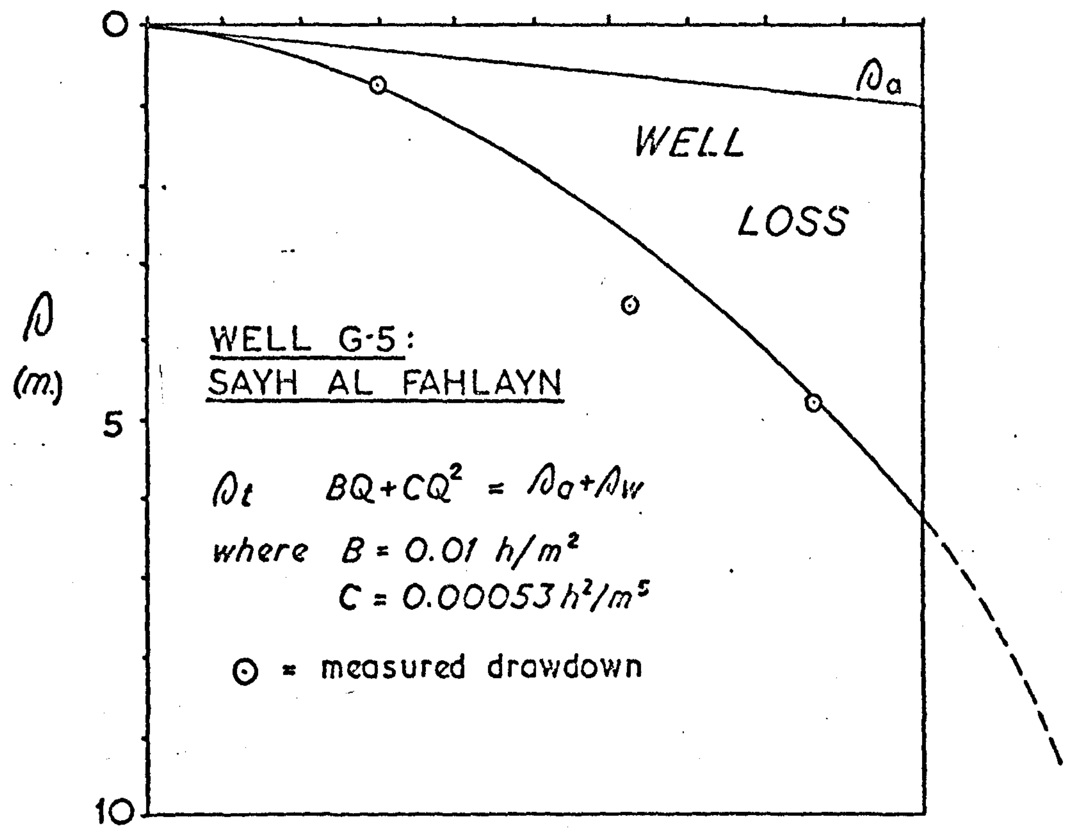


Fig. 6.21 Yield drawdown relationship for Sha'am and Sayh al Fahlayn.

reliable data, but it seems clear that high well losses are present and are probably due to insufficient development of the well after drilling. This feature would have some relevance to the calculation of transmissivity from pumped well data by constant rate testing and may explain some of the anomalous results. The well losses would be restricted to the drawdown phase so that one would expect transmissivity results determined from drawdown data to be lower than those determined from recovery data or from drawdown data in adjacent observation wells.

6.5 GROUND WATER MOVEMENT

The depth of water below ground level as measured in numerous existing wells varies from a maximum of 55 m in the wadi gravels at Burairat at the mountain front to less than 2 m near Ras al Khaimah, and from 20 m near Dhaid to 15 m near Adhieb. The hydrogeological evidence indicates that the aquifer system is generally unconfined, having a free water surface. Because of the layering and lenticular pattern of deposition, and the variation in the constituent material there may locally be partially confining conditions, but hydraulic continuity is believed to exist on an areal scale with a common water table.

An attempt has been made to draw the average steady state configuration of this water table in Figure 6.22 as ground water contours with interpolation between the well localities indicated for which SWH derived elevation data were available. In the Dhaid and Gharif plains area to the south the ground water contours run roughly parallel to the mountain front but swing to a NE - SW alignment as one proceeds towards the coast. This latter trend continues to the NE so that in the Jiri Plain from Idhn northwards the ground water contours run oblique to the mountain front. The fixed contour interval of 20 m used in Figure 6.23 serves to emphasise the change in hydraulic gradient along the inferred directions of flow. Thus in the Dhaid plain the gradient is 1 in 175, shallowing to 1 in 300 near Lamhah, and 1 in 600

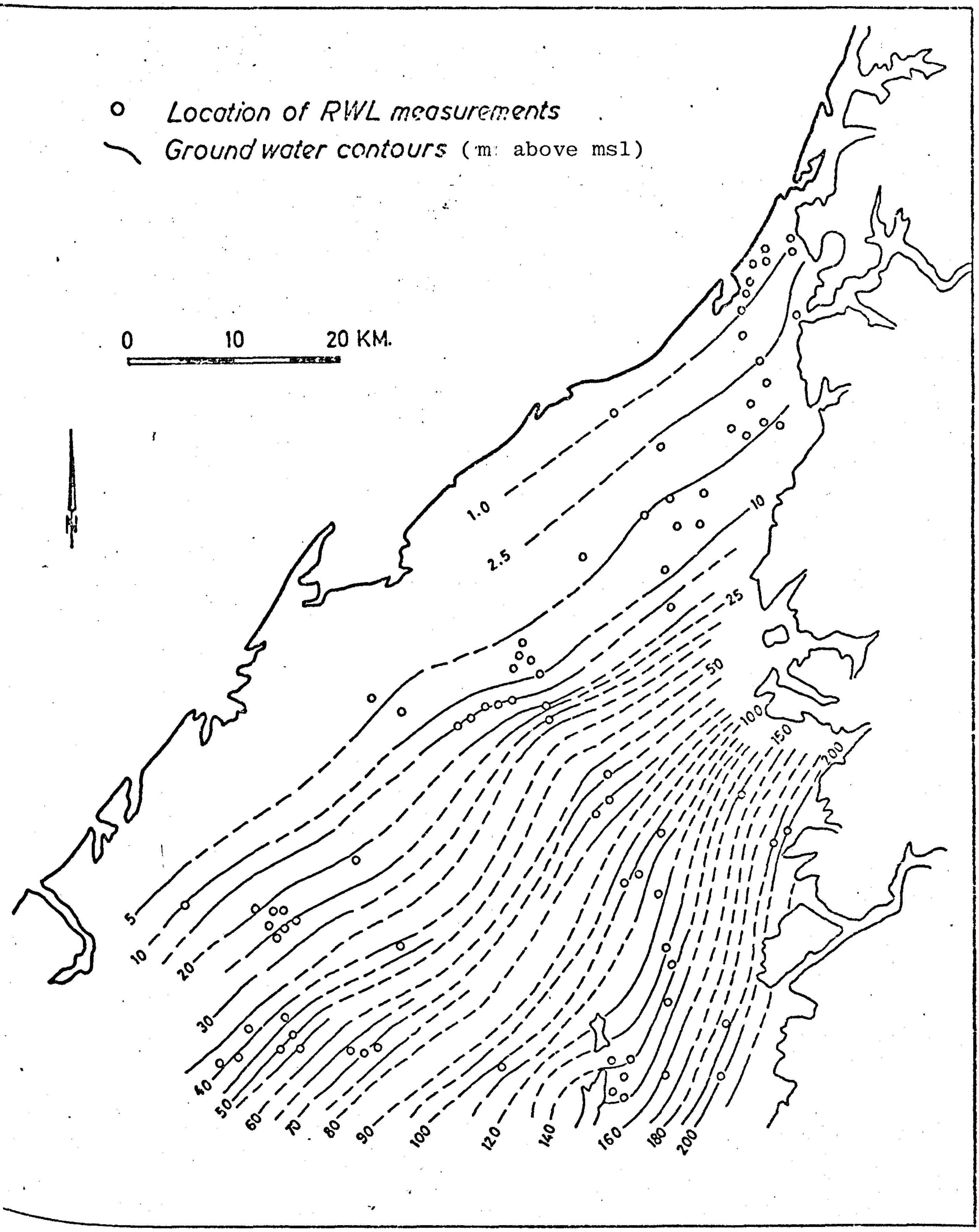


Fig. 6.22 Ground water contour map with locations of water level measurements.

some 10 km inland from the coastline. In the northern plains area the gradient is much shallower, being 1 in 1200 at Hamraniyah and closer to 1 in 2000 near Burairat.

The ground water contours may be regarded as lines of equipotential so that streamlines representative of ground water flow lines may be sketched at right angles to the contours to produce a ground water flow net. Such a flow net has been attempted in Figure 6.23 and the general directions of ground water movement are compatible with a recharge source along the mountain front. It is noticeable that there is no evidence of any build up at the mouths of the major wadis despite them being the prime source of replenishment water.

In the absence of information on the saturated thickness it is not possible to undertake a truly quantitative assessment from the flow net, though some inferences are possible. For instance, the reduction in gradient indicated by the wider spacing of the contours as one proceeds in a downstream direction is open to alternative interpretations. It could be due to an increase in the transmissivity (T) of the aquifer, but since this is the product of the hydraulic conductivity (K) and the saturated thickness (b), the change could be due to an increase in either or both components. Two flow channels have been selected to illustrate the principle, one each from the northern and southern plains, and they are indicated in Figure 6.23. Depending on the shape of the four-sided area formed by the intersection of a pair of contours and a pair of flow lines an index value related to 'transmissivity' has been assigned to each successive 'square' moving downstream from the index square value of 1. The range so encountered is from 0·4 to 1·6 for the northern flow channel, but from 1 to 6·7 along the southern flow channel. The alternative explanation is that the quantity of flow decreases downgradient which is only likely to occur when excessive quantities of water are removed artificially by pumping or naturally by evaporation. Given the 10 - 15 km wide coastal flats in the west where the water table is close to the surface,

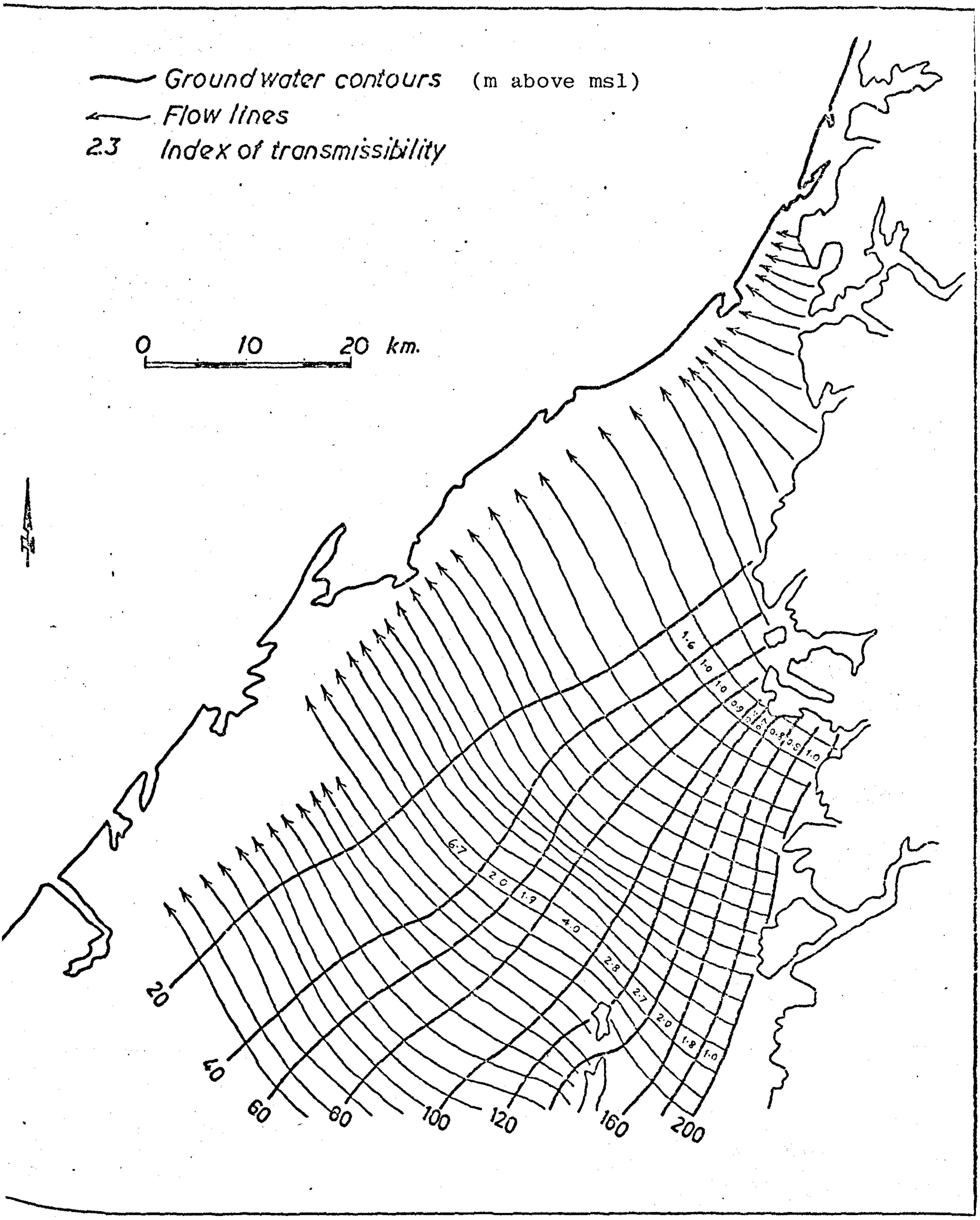


Fig. 6.23 Ground water flow-net for northern UAE.

then evaporation could certainly account for large scale withdrawals and it is unlikely that any significant issues of ground water ever reaches the coastline across the Sabkha flats.

Darcy's Law can be used in conjunction with the ground water contours to estimate the velocity of ground water movement by use of the equation $v = Ki$ where v = flow velocity, K = hydraulic conductivity, and i = gradient. With hydraulic conductivity ranging from negligible values up to 100 m /d or more, and hydraulic gradients varying between 0·001 and 0·005, one may by use of the extreme values obtain a range of ground water velocity up to 0·5 m/d. Even at the most rapid rate it would take over 100 years for water to travel the 20 km from the intake area at the foot of the mountains to the centre of Dhaid. Gradients are more shallow and conductivity values higher in the Gravel Plain (North) where with k = 190m/d and i = 0·0008, the velocity may be calculated to be 0·15 m/d which would take over 180 years for ground water to pass from Idhn to Hamraniyah. Only rarely have determinations been made for the age of the ground water in the area of study but tritium dating of the falaj water at Dhaid gave a pre-1954 date which is consistent with the calculated slow rates of movement.

6.6 GEOPHYSICAL SURVEYS

With such a paucity of subsurface geological information and an uneven distribution of such information as is available, indirect methods have been applied in the form of geophysical surveys. Three such surveys have been undertaken in the study area by Evans (1966), SMM (1971) and HTS (1975) and the districts and localities surveyed are shown in Figure 6.24. In all cases the geophysical method used was surface resistivity measurement, commonly in the form of expanding depth probes to provide information on lithology, aquifer geometry and aquifer properties. The method utilises the fact that resistivity is mainly dependent on the water present in the voids. In general, resistivity decreases with increased porosity, degree

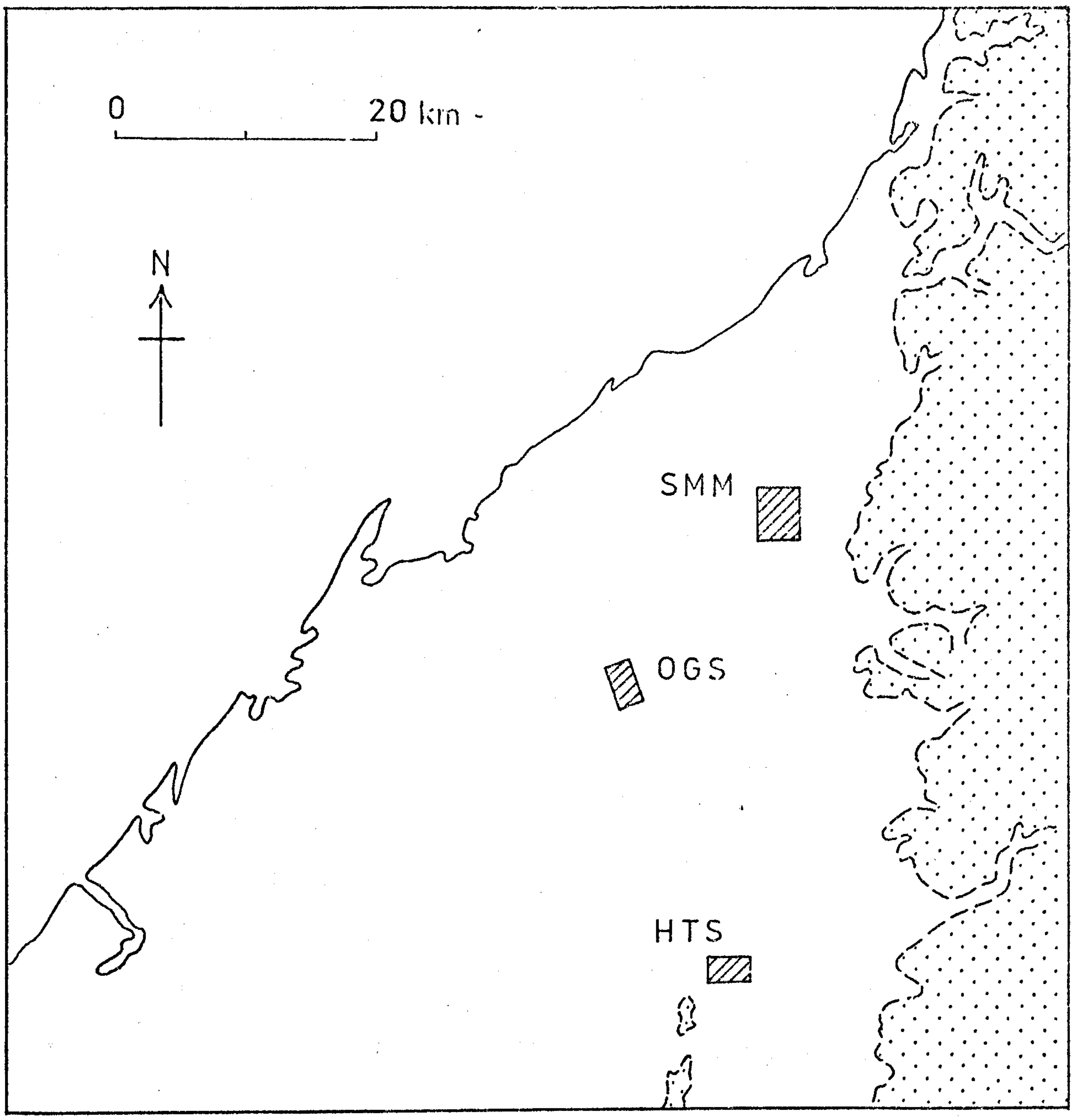


Fig. 6.24 Districts where geophysical surveys have been undertaken

of saturation, and the salinity of the contained water. In argillaceous (clayey) units, the resistivity is lowered by the presence of clay minerals and is often independent of the interstitial water salinity.

The work done by Evans (Overseas Geological Survey) was on behalf of the TSC Water Resources Survey and included a number of localities outside the current area of interest, though their results are relevant. He identified a number of practical operational difficulties that are applicable to surface resistivity work in arid regions. Constant electrode traverses were considered to be too susceptible to lateral variations within the shallow depths to provide any information on water-bearing strata, so that all electrical resistivity measurements were made with an expanding electrode probe. Of the two most commonly used electrode configurations (despite the apparent advantages of the Schlumberger method) the Wenner layout was used because of 1) near surface resistivity anomalies, 2) rapid decrease in resistance with depth, and 3) the lack of multi-layer curves for the Schlumberger layout. Dry surface conditions made it exceedingly difficult to get sufficient current into the ground for resistivity measurements to be made. Even with 2 ft deep stakes moistened with salt water, the stake resistance was in the range of 5000 to 10000 ohms, though after rain this was reduced to 1000 ohms. It is, of course, not practicable to undertake resistivity work only after rain in this area of infrequent precipitation. In the interpretation of the results, the suggestion was made that horizontal layering existed in the gravel plains with large resistivity contrasts and many thin layers for which the standard matching curves were not designed. Evans concluded that the resistivity method can provide information on large scale lithological changes in shallow water-bearing strata, but was not recommended for identification and mapping of small salinity variations in the water of such strata. The most useful result of the survey was the detection of significant amounts of clay within the subsurface sequences, and the proposal

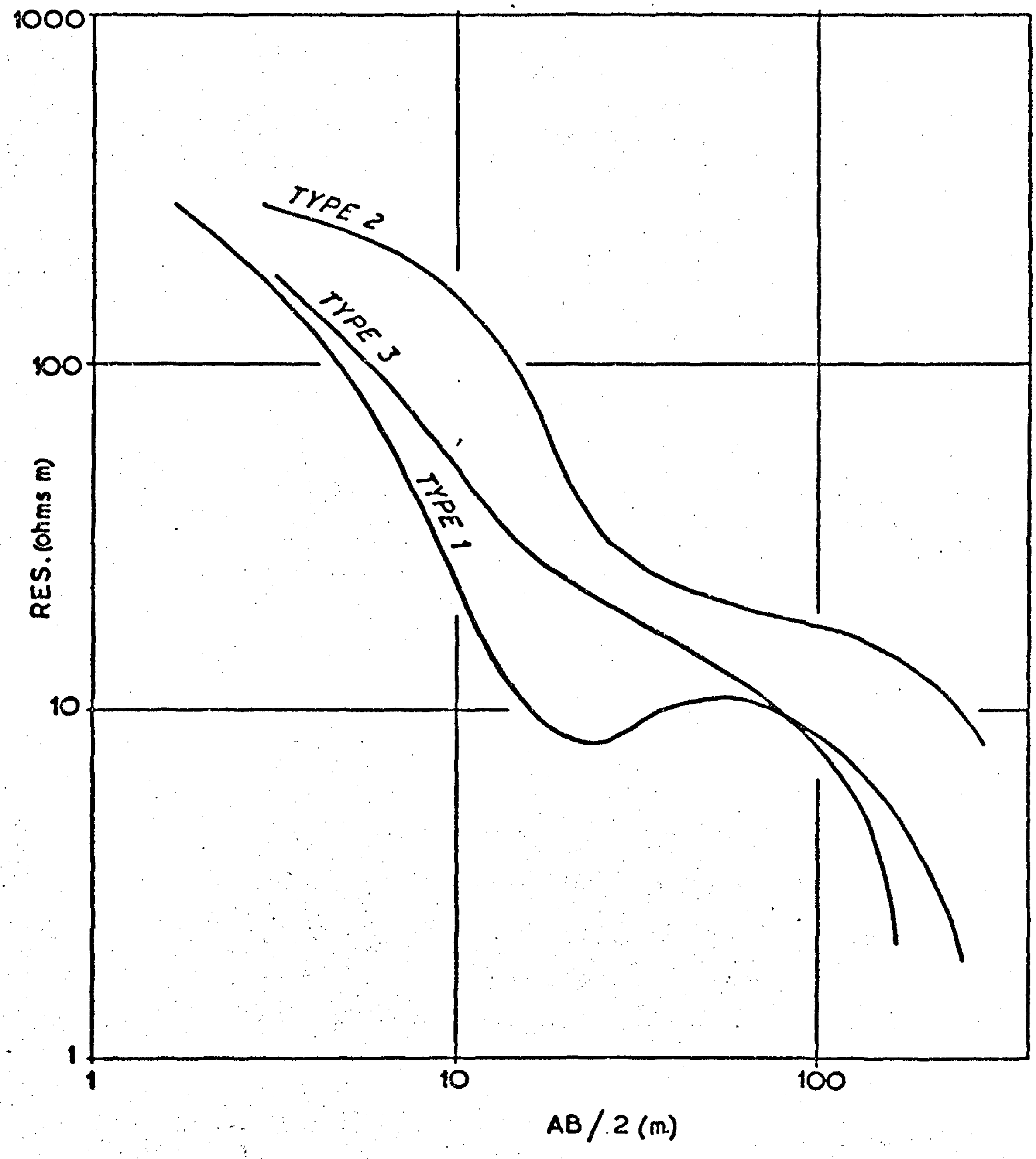


Fig. 6.25 Examples of depth probe resistivity curves from Hamraniyah

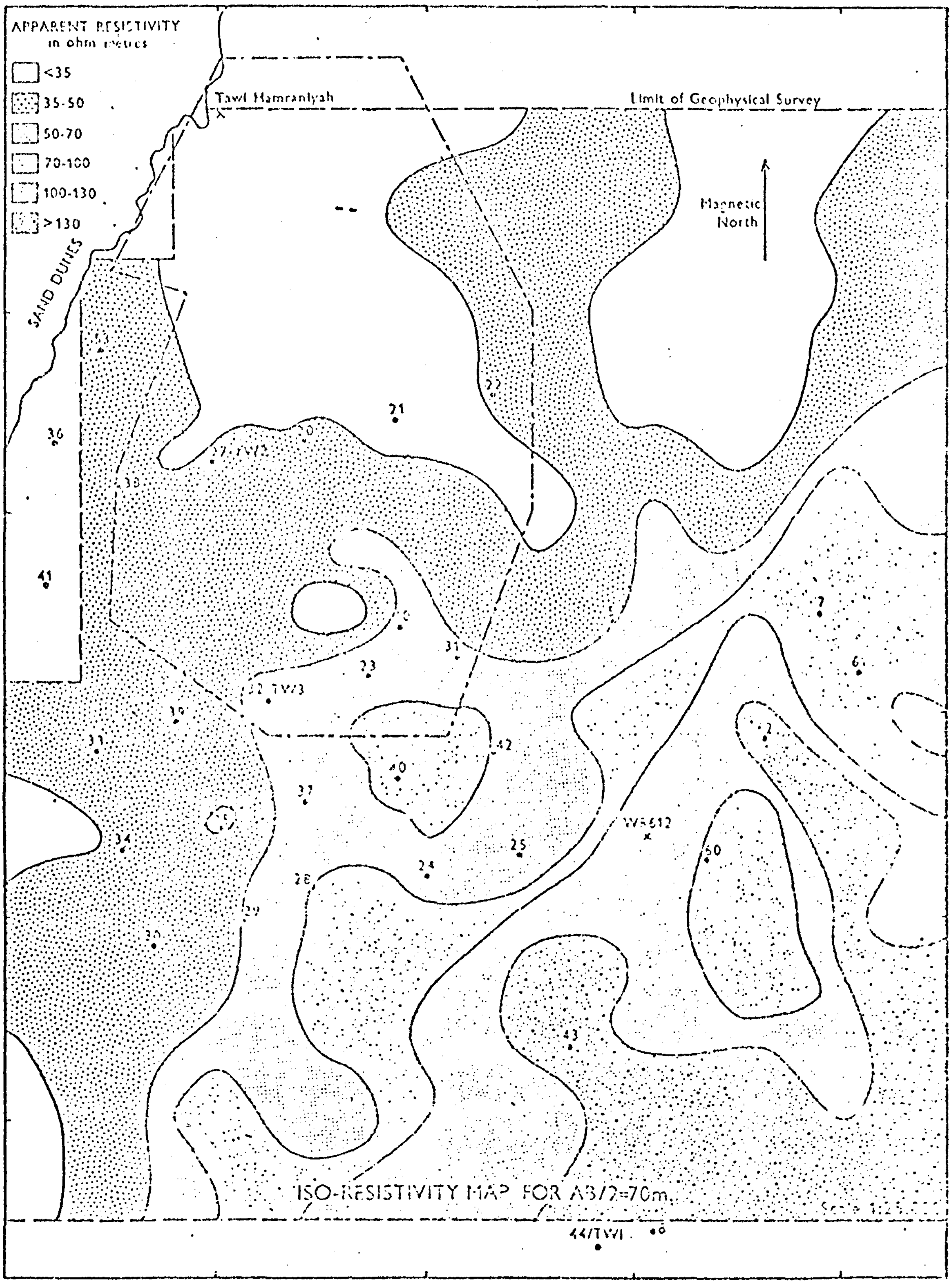


Fig. 6.26 Iso-resistivity map of Hamraniyah (from MMP, 1971)

that higher resistivity is related to higher aquifer yield. It was emphasised that resistivity work should be continued only if the initial field data curves are capable of being interpreted in terms of known hydrogeological conditions.

The resistivity survey carried out as part of the Hamraniyah irrigation project (SMM, 1971) aimed at providing information on ground water conditions and subsurface lithologies. A D.C. high powered Terrameter instrument was used with the Schlumberger electrode configuration, though difficulties were encountered in making electrical measurements due to 1) the high contact resistance between the electrodes and the ground, and 2) the varying self potential between the potential electrodes, particularly in windy conditions. Examples of the three types of curves found are illustrated in Figure 6.25; type 1 is that most commonly encountered and is suggestive of at least four layers ranging downwards in the order, high, low, intermediate, low; while curves type 2 and 3 are similar but with the uppermost low resistivity horizon absent. The accurate interpretation of the details of the curves was difficult but gave an acceptable general picture. It appears as if the resistivity method is unable to resolve the depth, thickness and nature of an alternating sequence of thin gravels, sands, silt and clay. To assist in the general interpretation, an iso-resistivity map with AB/2 = 70 m was prepared and is reproduced as Figure 6.26. It indicates lobes of high resistivity extending into the survey area from the south east and interprets them as areas of fresher water fingering along more permeable channels into a more saline area. The most recent resistivity work was undertaken by HTS in 1975 as part of a feasibility study in connection with the 'falaj' at Dhaid in order to obtain information on the lithology and depths of the various strata likely to be present. It was hoped that the contrast between the highly resistive gravels and the highly conductive dolomite would allow the base of the 'aquifer' to be mapped. The Schlumberger sounding configura-

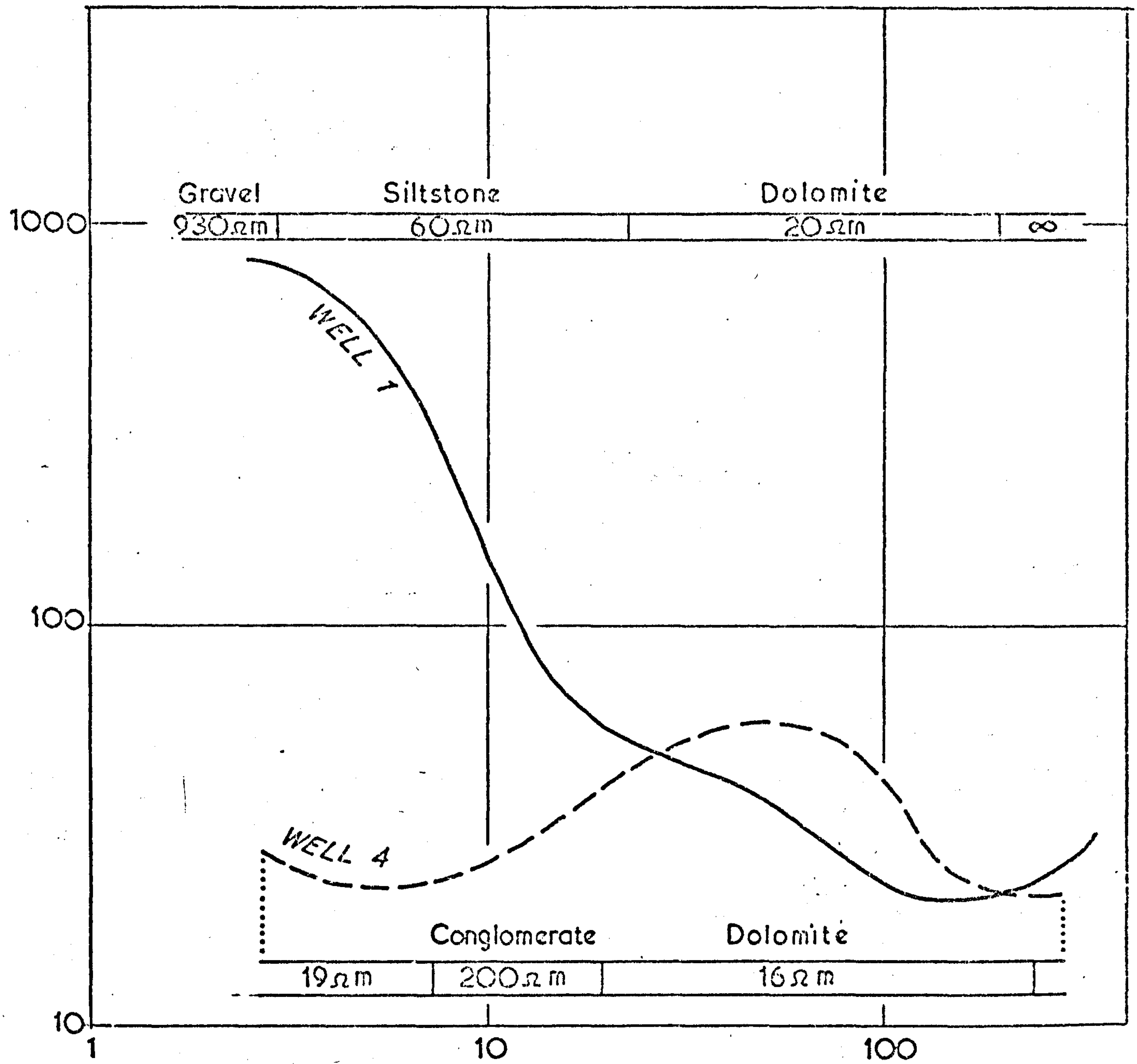


Fig. 6.27 Calibration depth soundings at Dhaid

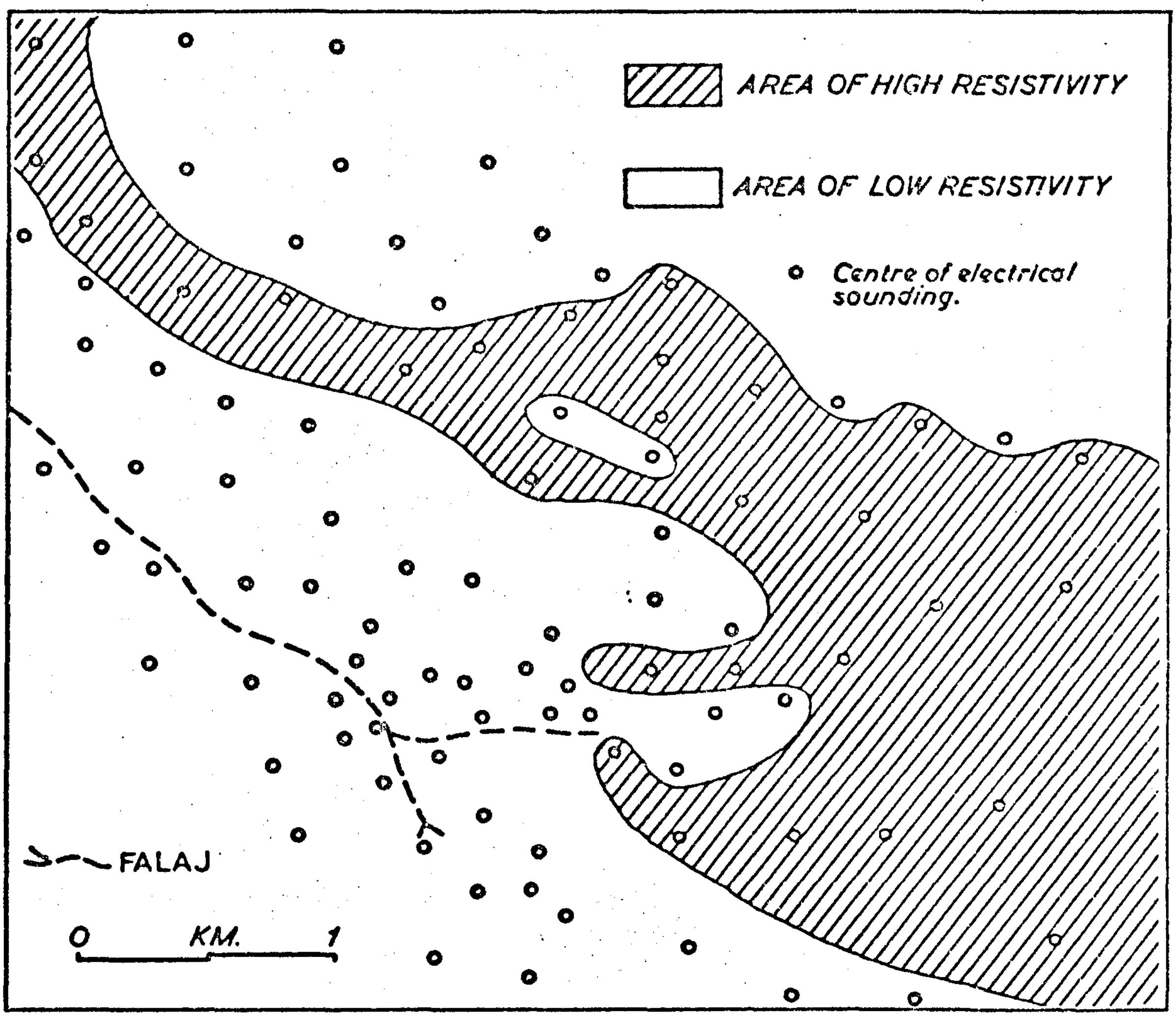


Fig. 6.28 Iso-resistivity map of Dhaid

tion was used in conjunction with an improved high power DC resistivity unit. The results were interpreted by matching the field data to standard curves after soundings had been made adjacent to two wells for calibration purposes (Figure 6.27). Wells 1 and 4 had negligible and good yields respectively, and the availability of ground water in significant quantities is interpreted as being due to the resistivity high in Well 4 formed by the conglomerate. Such correlation between high resistivity and high yields is not everywhere the case, though the proposal seems generally valid. An iso-resistivity map was prepared (Fig.6.28) but for successful results must be used in conjunction with knowledge of the depth to the water table and general information on hydrogeological conditions in the aquifer gained from adjacent wells.

7. HYDROCHEMISTRY

7.1 Introduction

7.2 Chemical Constituents of Ground Waters

7.3 Thermal and Mineral Waters

7.4 Classification of Natural Waters

7.5 Quality Criteria and Use Limitations

7. HYDROCHEMISTRY

7.1 INTRODUCTION

Any study of the chemistry of ground water(s) of an area is heavily dependent on the data that are available in the form of chemical analyses. From the various sources consulted, a total of ninety eight full analyses were used in the preparation of this chapter, together with up to thirty partial analyses. The full analyses were almost entirely undertaken in Britain, while the partial analyses were all made in the UAE, either in local laboratories or with the use of field analytical kits. Analysts in Britain were Robertson Research Limited, Counties Public Health Laboratories, Huntings and the Geology Department of University College London. A particular debt is acknowledged to the former Trucial States Council who, through their Water Resources Survey organised by Sir William Halcrow, ensured that a data base was initiated in 1966. Without such work this study would have lacked serious factual information. The same procedure was adopted in reporting the results of the full chemical analyses, with electrical conductivity (EC), total dissolved solids (TDS), total hardness, alkalinity and pH values determined on arrival at the laboratory. Chemical analysis was determined separately for the alkaline earth metals of calcium and magnesium, and also separately for the alkalis of sodium and potassium, so that it was not necessary to rely on determinations by difference. On the anion side, analysis was carried out for the strong acid radicles of sulphate, chloride, nitrates and also for the weak acid radicles of carbonate and bicarbonate. Fluoride was determined in all analyses, and iron, manganese and boron in most, with a number of trace elements tested for in the earlier analyses. The distribution of sites from where samples were taken is shown in Figure 7.1 to have representatives of all the natural units identified previously. The analytical data were commonly reported in milligrams per litre (mg/l) or

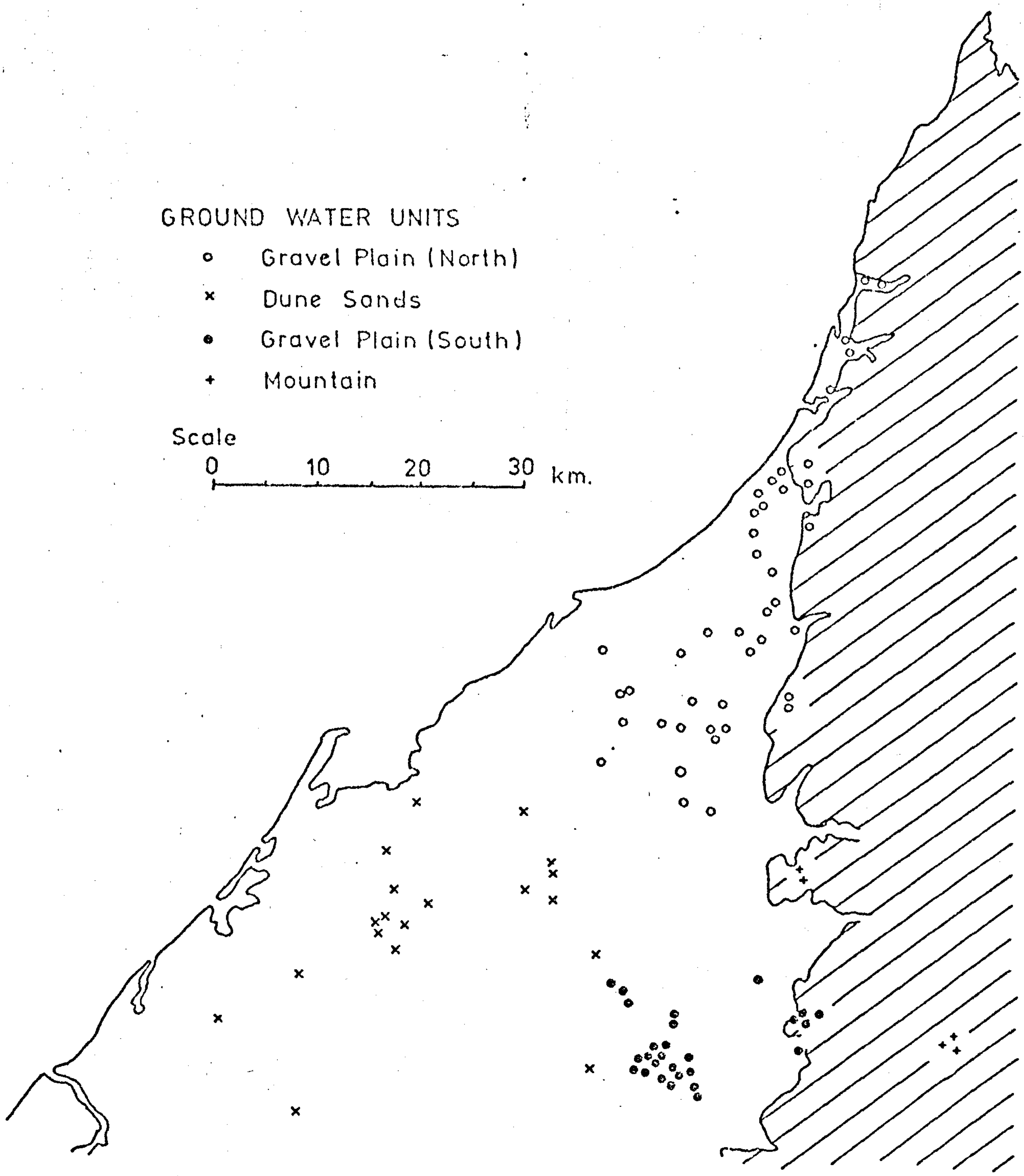


Fig. 7.1 Distribution of localities from which water samples were taken for chemical analysis

parts per million (ppm) and have been used in this form in the description of the chemical constituents. However, for the more scientific aspects of classification and interpretation of the genesis of the waters, it was necessary for all the analyses to be converted and expressed as milliequivalents per litre (m.eq/l) or equivalent per million (epm). With data expressed in this ionic form it is possible to check on the accuracy of the analysis since the sum of the cations should approximately equal the sum of the anions. Furthermore, when converted to percentage m.eq/l values, the data are in a form that is most convenient for plotting and classification purposes. The comprehensive tabulation of all the analytical results is given in Appendix II, with the data for each analysis reported in mg/l, m.eq/l, and percentage m.eq/l. The results have been summarised in Tables 7.1 to 7.4 which give mineral, anion and cation values of major and minor elements and physical properties of the ground waters from the respective physiographic units.

7.2 CHEMICAL CONSTITUENTS OF GROUND WATERS

Specific Electrical Conductance (EC) or conductivity, is the ability of a substance to conduct an electric current and is usually reported as 'reciprocal ohms' or 'mhos' at a reference temperature. Because natural waters commonly have low values of less than one mho, it is usual to report results in micromhos at the standard temperature of 25^{o}C. The range of conductance encountered in the study area is from 370 to 13,000 micromhos, but there would appear to be some differentiation between the geological - physiographic units previously defined and illustrated in Figure 3.1.

The data tabulated below show that the lowest values relate to the Mountain unit and the highest values are from the Gravel Plain (North) and Dune Sands, with the conductance of Gravel Plain (South) waters occupying an intermediate position. The interpretation and significance of these

TABLE 7.1 : Summary of minimum, mean and maximum values of major and selected minor elements and physical properties from ground waters of the Dune Sand unit.

Item	units	minimum	mean	maximum
EC	umho/cc	950	5100	10773
TDS	mg/l	622	3477	7554
Hardness	mg/l $CaCO_3$	180	647	1972
Alkalinity	mg/l $CaCO_3$	155	262	535
Ca	mg/l	22	63	169
Mg	mg/l	17	116	376
Na	mg/l	150	832	1710
K	mg/l	8	30	84
CO_3	mg/l	nil	8	162
HCO_3	mg/l	189	302	653
SO_4	mg/l	61	551	1410
Cl	mg/l	120	1312	3000
NO_3	mg/l	1	23	230
F	mg/l	0.07	0.65	1.3
Fe	mg/l	0.04	0.41	2.9
Mn	mg/l	nil	0.05	0.23
B	mg/l	0.03	0.47	1.97

TABLE 7.2 : Summary of minimum, mean and maximum values of major and selected minor elements and physical properties from ground waters of Gravel Plain (South) Unit.

Item	Units	Minimum	Mean	Maximum
EC	umhos	419	-	2000
TDS	mg/l	392	714.3	1526
Hardness	mg/l	188	-	748
Alkalinity	$(CaCO_3)$	132	-	431
Ca	mg/l	14.0	23.4	33.7
Mg	mg/l	16.8	48.2	172.3
Na	mg/l	23.0	137.1	308.1
K	mg/l	3.5	7.3	16.8
CO_3	mg/l	nil	22.4	129.2
HCO_3	mg/l	161.0	219.8	335.0
SO_4	mg/l	28.8	86.2	230.0
Cl	mg/l	58.0	199.8	595.0
NO_3	mg/l	Tr	14.1	44.0
F	mg/l	Tr	0.3	0.6
Fe	mg/l	0.02	0.3	1.92
Mn	mg/l	nil	0.03	0.08
B	mg/l	0.08	0.13	0.20

TABLE 7.3 : Summary of minimum, mean and maximum values of major and selected minor elements and physical properties from ground waters of the Gravel Plain (North) Unit.

Item	Units	Minimum	Mean	Maximum
EC	umhos	1064	-	13000
TDS	mg/l	525	2885	10200
Hardness	mg/l $CaCO_3$	122	-	1739
Alkalinity	mg/l $CaCO_3$	160	-	600
Ca	mg/l	18.6	117.4	523
Mg	mg/l	14.5	86.1	260
Na	mg/l	175.0	856.3	3200
K	mg/l	7.0	24.4	84
CO_3	mg/l	0	5.1	30
CHO_3	mg/l	92	358.7	732
CHO_3	mg/l	60	791.9	1488
Cl	mg/l	237	1347.6	6607
NO_3	mg/l	0.2	25.2	96.5
F	mg/l	Tr		5.0
Fe	mg/l	0.02		5.3
Mn	mg/l	nil		0.7
B				

TABLE 7.4 : Summary of minimum, mean and maximum values of major and selected minor elements and physical properties from ground waters of the Mountain Unit.

Item	Units	Minimum	Mean	Maximum
EC	umhos	366	734.5	1410
TDS	mg/l	262	539.6	1096
Hardness	mg/l	45	203.1	421
Alkalinity	($CaCO_3$)	84	-	254
Ca	mg/l	4.8	15.3	42.3
Mg	mg/l	7.8	39.9	76.5
Na	mg/l	11.8	94.7	204.0
K	mg/l	1.5	4.8	9.8
CO_3	mg/l	nil	7.0	30.0
HCO_3	mg/l	65.0	162.2	309.0
SO_4	mg/l	4.0	59.1	170.0
Cl	mg/l	45.0	156.9	362.0
NO_3	mg/l	0.4	5.3	22.0
F	mg/l	Tr	-	0.5
Fe	mg/l	0.02	0.15	0.28
Mn	mg/l	nil	-	0.04
B	mg/l	0.02	0.07	0.22

unit	samples	range (mmhos)	mean (mmhos)
Dune Sands	19	950 to 10800	5100
Gravel Plain (N)	45	1064 to 13000	-
Gravel Plain (S)	27	419 to 2000	-
Mountain	7	366 to 1410	735

results is best left to the next section.

Total Dissolved Solids (TDS) and its synonyms are used to express the total concentration of dissolved minerals in water. The 'solids' may be determined from the weight of dry residue after a known quanity of water has been evaporated. Alternatively they may be calculated by summation of these concentrations of the separate elements in the sample, though the majority of values used in this study have been determined by the first method.

The presence of dissolved mineral matter with their electrically charges ionic species in water will increase the conductance of that water. Indeed, the amount of mineral matter in solution may be so high as to render the water unsuitable for certain purposes, and this feature of waters from the study area is considered in more detail in section 7.5 as ground water quality and use limitations.

Since the conductance of a solution is proportional to ion concentration, the measurement of specific conductance will provide an indication of dissolved solids content. It is not surprising, therefore, that the range of TDS values tabulated below from the study area shows an areal pattern similar to that demonstrated for the EC measurements.

The relationship between TDS and EC is simple and direct in solutions of single salts, but ground waters are only rarely simple solutions and the specific conductance of solutions containing different minerals will itself

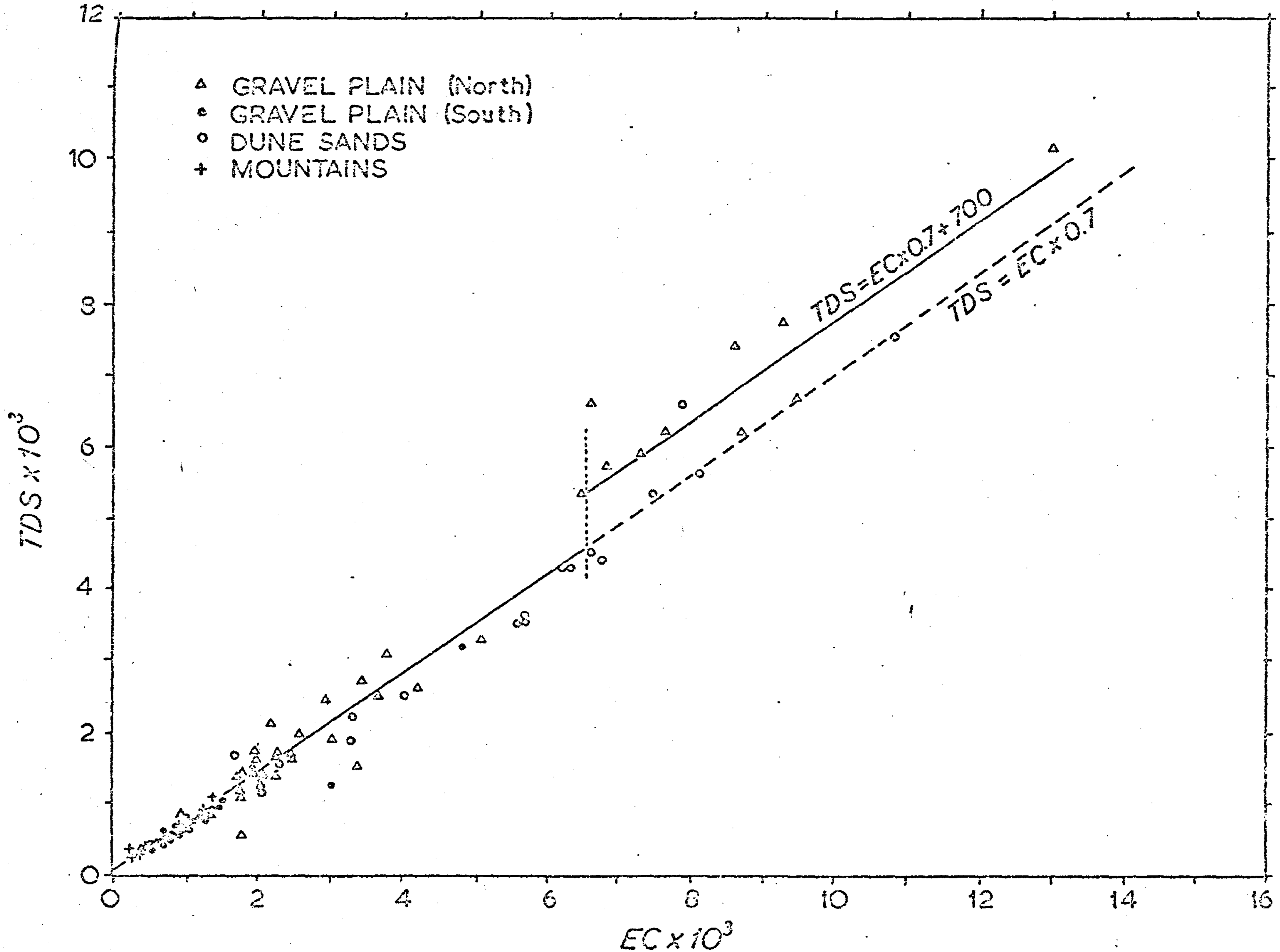


Fig. 7.2 Plot of TDS against EC for all analyses from study area

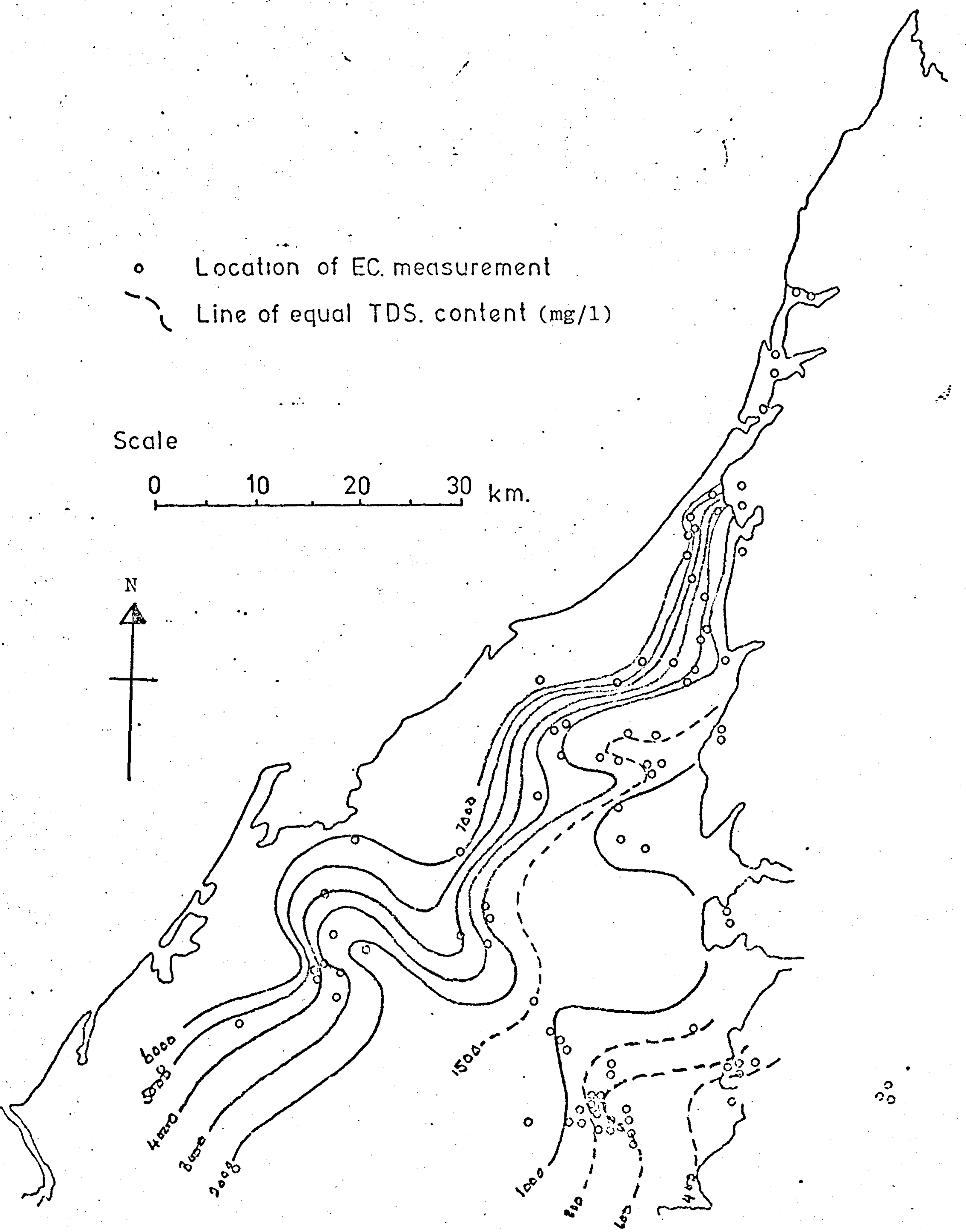


Fig. 7.3 Map showing lines of equal TDS content.

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	622 to 7554	3477
Gravel Plain (N)	45	525 to 10200	2885
Gravel Plain (S)	27	354 to 3204	714
Mountain	7	262 to 1096	540

be different. Figure 7.2 shows a plot of TDS against EC for all the analyses available from the study area. A line of best fit gives a relationship having the form TDS = 0·7 EC for waters with a TDS content less than 5000 mg/l, and TDS = 0·7 EC + 700 for waters with a TDS content greater than 5000 mg/l. In Figure 7.3 an attempt has been made to interpolate lines of equal TDS or solute concentration from the individual sample locations.

Calcium (Ca) is the principal cation on most fresh ground waters since the element is very widely distributed in soil and rock minerals. The most common forms of calcium in sedimentary rocks are the carbonates, particularly found in limestone and dolomite which are prevalent in the study area either as consolidated rocks or as constituent of the minerals of many igneous rocks; the slower rate of decomposition of such rocks means that the calcite concentration is lower than in waters associated with carbonate sediments. A tabulation similar to those previously presented gives the essential details of calcium distribution in waters of the study area and from both the range and mean values one can detect a prevailing pattern, with high

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	22 to 169	63·0
Gravel Plain (N)	45	18·6 to 523	117·4
Gravel Plain (S)	25	14·0 to 33·7	23·4
Mountains	7	4·8 to 42·3	15·3

values in the Gravel Plain (N) decreasing through the Dune Sands and Gravel Plain (S) to the low values of the Mountain Unit.

Magnesium (Mg) is more soluble than calcium and is commonly derived from such sedimentary rocks as dolomite and limestone or fragments of the same. It is also a typical constituent of the ferromagnesian minerals of igneous rocks such as the olivines, pyroxenes and amphiboles of the Semail rocks. Specific magnesian mineral species are associated with serpentine and magnesite, both of which are common from the southern part of the mountains in the study area.

The details of magnesium distribution for this area are tabulated below and may be seen to be high as well as conforming to the typical pattern:-

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	17·0 to 376·0	116·0
Gravel Plain (N)	45	14·5 to 260·0	86·1
Gravel Plain (S)	27	27·0 to 172·3	48·2
Mountains	7	7·8 to 76·5	39·9

Sodium (Na) is the most abundant member of the alkali-metal group and being exceptionally soluble tends to remain in solution. It is found in feldspars that are typical of many igneous rocks, though these are usually resistant to chemical attack. In sedimentary rocks, it is uncommon except in evaporites and argillaceous sediments. The tabulated details below from the study area show an interesting feature:-

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	150 to 1710	832·0
Gravel Plain (N)	45	175 to 3200	856·3
Gravel Plain (S)	27	23 to 210	137·1
Mountains	7	11 to 204	94·7

The association of the Mountain unit waters with those of the Gravel Plain

(South) and the Duna Sands waters with those of the Gravel Plain (North) is even more emphatically delineated. This time, however, the consistently high values for sodium cannot be explained as easily as those of the previous constituents, particularly in view of the apparent lack of evaporites.

Potassium (K) concentrations in most natural waters are much lower than those of sodium because potassium is only taken into solution with great difficulty. This is confirmed from the study area in the tabulated details below which again confirm the prevailing pattern:;

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	8·0 to 84·0	30·0
Gravel Plain (N)	45	7·0 to 84·0	24·4
Gravel Plain (S)	27	3·5 to 17·0	7·3
Mountains	7	1·5 to 9·8	4·8

Sulphate (SO_4) is usually derived from gypsum or anhydrite in sedimentary strata, or from metallic sulphides in igneous rocks. The essential details from the available analyses confirm the prevailing pattern, and as with sodium there is some difficulty in reconciling the high values directly or indirectly to the rocks and strata from the study area which are deficient in evaporites.

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	61 to 1410	551·0
Gravel Plain (N)	45	60 to 1488	791·9
Gravel Plain (S)	27	33 to 230	86·2
Mountains	7	4 to 170	59·1

Chloride (Cl) is the most important and widely distributed member of the halogen group in natural waters, though neither igneous rocks nor sedimentary strata (other than some evaporites) provide high concentrations to normal ground waters. The expected pattern of distribution within the study area is confirmed by the details tabulated below:-

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	120 to 3000	1312·0
Gravel Plain (N)	45	237 to 6607	1347·6
Gravel Plain (S)	13	58 to 595	200·0
Mountains	7	45 to 362	156·9

Fluoride (F) another member of the halogen group, is much less abundant than chloride in natural waters though is more abundant in rock minerals. The mineral has a low solubility and as may be seen from the tabulated details is present in the study area in low values.

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	0·07 to 1·3	0·65
Gravel Plain (N)	45	Tr to 5·0	-
Gravel Plain (S)	13	Tr to 0·6	0.3
Mountains	7	Tr to 0·5	Tr

Nitrate (NO_3) concentrations in ground water are commonly not related to geological strata and rocks but have been variously attributed to leguminous vegetation in arid regions, to nitrogenous fertilisers and particularly to pollution from human and animal sources. The higher values for nitrate in the agriculturally active parts of the study area seems to favour the downward leading of excess fertilisers, but the association of chloride and sulphate points to pollution as a more likely cause.

unit	samples	range (mg/l)	mean (mg/l)
Dune Sands	19	1·0 to 230·0	23·0
Gravel Plain (N)	45	0·2 to 96·5	25·2
Gravel Plain (S)	9	Tr to 44·0	14·1
Mountains	4	0·4 to 22·0	9·3

Chemical constituents of waters from the deep aquifers

An equivalent study of the chemical constituents in waters from the various deep consolidated strata cannot be undertaken due to the non-availability of data which is normally restricted by the petroluem exploration companies. However, a limited amount of information has been conditionally supplied to the author from which it is possible to reconstruct the probable hydrochemical conditions in those parts of the study area obscured by Quaternary deposits.

The data are tabulated below for locations to the south-west of the study area that must remain unspecified so as to preserve the confidentiality of the information. The strata are all lithologically equivalent to those likely to be found within the study area. The increase in TDS content

Formation	Age	Sample Depth (m)	TDS (ppm)
Lr. Fars. Fm.	Mio-Olig.	200	> 150,000
Dammam Fm.	Ur. Eoc.	500	brines
Aruma Gp.	M. Cret.	1300	< 180,000
'limestones'	Lr. Cret.	3000	< 200,000

with depth to the aquifer is clearly indicated, but it is the enormity of the dissolved ion concentration that is the most notable feature. Their description as 'black sulphurous brines' contains no hope of their possible use for any normal purpose, even from strata at the relatively shallow depth of some 200 metres below land surface.

More detailed analyses of typical waters from two separate fields are tabulated below with their localities again withheld for reasons of confidentiality. Whilst highly interesting as hydrochemical examples of saline waters, they show the futility of expecting naturally potable ground water from the deeper aquifers of the 'foreland' region.

Sample	1	2	3	4
pH	7·2	7·6	7·1	6·2
TDS (mg/l)	3,554	6,500	157,638	240,130
Fe	nil	2	0·86	250
Ca (mg/l)	108	421	1303	20,055
Mg	97	50	1,969	3,158
Na + K	1,035	1,837	56,766	67,098
CO_3 (mg/l)	nil	nil	nil	nil
H_2CO_3	nil	nil	nil	nil
SO_4	676	1,310	8,395	286
Cl	1,484	2,730	89,342	148,210

Interpretation of results.

It is difficult to assimilate all the previous descriptions and tabulation, but by graphically presenting the information in the form of pattern diagrams it is easier to visually identify significant trends and correlations. Plots of the maximum and minimum values (mg/l) of the major elements are produced in Figure 7.5 to show differences in their ranges of concentration for four ground water units. It should be noted that the plots have had to be drawn on a common logarithmic base in order to allow the essential details to be shown, and this scale tends to subordinate what are actually marked differences. Nonetheless, it appears as if the Gravel Plain (North) waters have considerable affinity with those of the Dune Sands, whereas waters from the Gravel Plain (South) appear to have more in common with those from the Mountain area. Figure 7.6 shows plots of the mean values

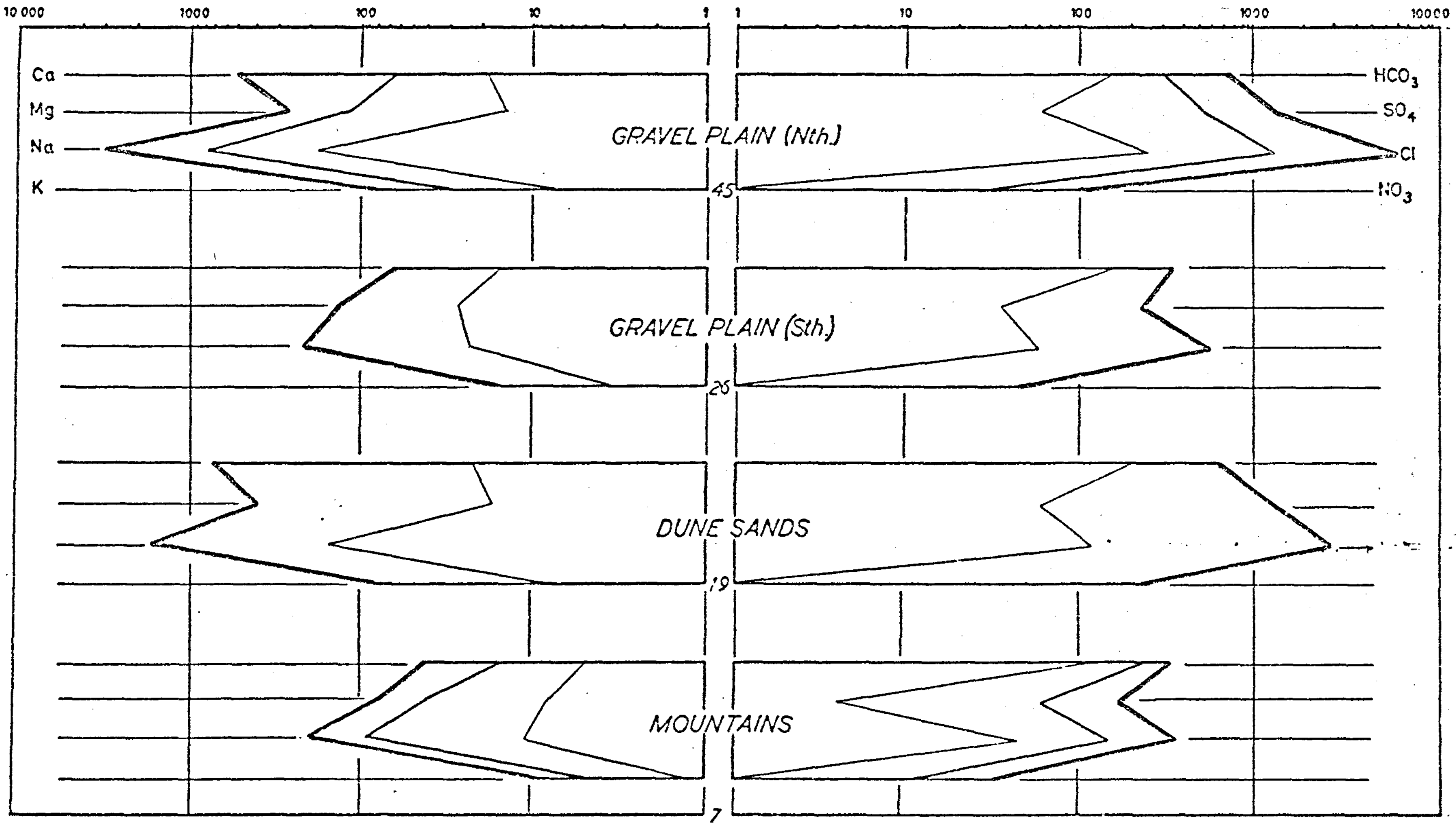


Fig. 7.4 Logarithmic distribution of ranges of concentrations of major elements in study area

(mg/l) of the same elements for the same four units, contrasting with the mean value of waters from the deep consolidated formations of the 'foreland' and a typical Arabian Gulf water. Again the Mountain and Gravel Plain (South) waters are very similar, with the Gravel Plain (North) and Dune Sand waters being identical in all respects and having a character that is similar in proportions though not in quantities of constituents to the sea water sampled from near Ajman. The mean of waters representing the deep aquifers to the immediate west of the study area are totally unlike any of the ground waters from the area investigated.

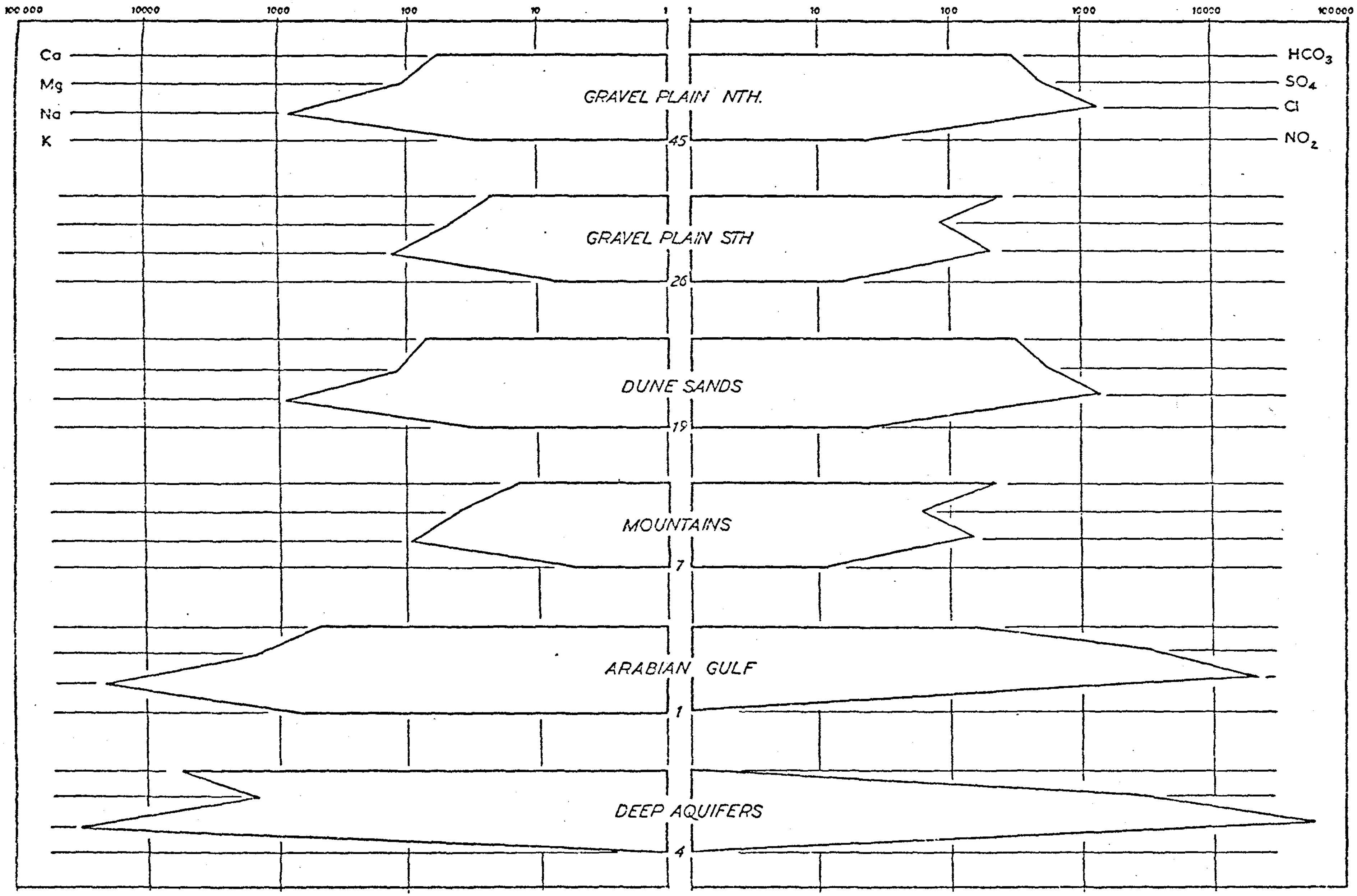


Fig. 7.6 Logarithmic distribution of mean values of concentrations of major elements in waters from study area, deep aquifers and sea

7.3 THERMAL AND MINERAL WATERS

The village of Khatt, located at about 30 m above mean sea level at the foot of the mountain range is particularly well known throughout the UAE for its thermal springs. These are natural issues of ground water that emerge from the limestones and have been modified in a manner described and illustrated in the following chapter. The normal temperatures of ground water in the northern UAE ranges between 26°C and 32°C, but the waters near Khatt are warmer by some 10°C, and this is not restricted to the spring waters.

The spring water temperatures have been recorded intermittently since 1960, and although the spring discharges fluctuate seasonally, there is no evidence of any significant daily or seasonal change in temperature. Bearing in mind that different instruments have been used by different persons, there is little significance to be read in the different values tabulated below for the major springs. The highest temperatures were found in the

source	Feb. 1966	Nov. 1975
northern spring	38·5°C	40·1°C
central spring	-	39·9°C
southern spring	39·5°C	39·3°C

bottom of the springs, and samples from the top or sides are regularly 0·2 to 0·4°C lower.

Water temperatures in wells in the adjacent district also reflect the higher values of the springs with the Federal MEW water supply borehole to the north of the village having a temperature of 39·7°C at 25 m below surface. These high temperatures decrease radially away from the village, so that some 700 m to the south the temperature of well water has fallen to 35·6°C. Close to the foot of the mountains 3500 m north of Khatt the temperature of the ground water is 31·1°C, while 3000 m to the west of the village the ground water temperature of 25·6°C is close to the mean annual air temperature.

Although the TDS content of the Khatt thermal waters is in excess of 1500 mg/l, one does not immediately think of the word 'mineral' to describe such water. Nevertheless, because of possible commercial, if not therapeutic reasons a sample of the water from the southern spring was collected in October 1975 by a firm of German consulting engineers and sent for detailed analysis to the Fresenius Institute in West Germany with the results given in Table 7.5.

According to the German Spa Committee definition for spas, convalescence centres and medicinal wells, the Khatt water can be regarded as a 'medicinal' water to be described in the chemical sense as a 'sodium-chloride thermal water'. Furthermore, the 'Table Water Regulations' allow the water to be designated as 'mineral water'. Constituents such as iron, arsenic, sulphur and carbon dioxide are not present in sufficiently large values for them to have special therapeutic effects. The bromide content of 1·25 mg/l is noteworthy, and the value of 0·73 mg/l for fluoride would be more beneficial than detrimental. Ammonium was not traceable while nitrite and nitrate values are within international limits. Two further samples for bacteriological analysis were taken in November, 1975, in sterile vessels and despatched by air freight to Germany for analysis. Upon arrival at the laboratory the water samples were found to contain coliform bacteria and some worms, possibly derived from the bathing that takes place in the springs. Any commercial exploitation of these waters would obviously have to ensure better protection against human pollution. Based on the use that is made of similar waters in Europe, the Khatt water may be suitable for drinking cures, medicinal baths, for inhalators and for motional thermal baths.

So far as the UAE is concerned, the Khatt district is unique in having such high ground water temperatures, yet there are no obvious hydrogeological conditions that can explain such an unusual response. The combination of folding, faulting and thrusting in the Musandam Group rocks immediately east

Quantitative Chemical Investigations after Preceeding Qualitative Examination

One kg. of the water (the thermal water) of Khat/UAE contains:

Cations:	milligrams / kg mg/kg	milligrams per litre/kg mval/kg	milligrams per litre - % mval/kg
Sodium (Na^+)	375,1	16,32	69,53
Potassium (K^+)	7,95	0,2033	0,87
Magnesium (Mg^{2+}) ..	32,1	2,641	11,25
Calcium (Ca^{2+})	84,8	4,232	18,03
Strontium (Sr^{2+}) ..	3,21	0,0733	0,31
Iron (Fe^{2+})	0,08	0,0029	0,01
Sum :		23,47	100,0

Anions:			
Fluoride (F^-)	0,73	0,0384	0,16
Chloride (Cl^-) ...	541,9	15,29	65,13
Bromide (Br^-)	1,25	0,0156	0,0
Jodide (J^-)	0,088	0,0007	-
Nitrite (NO_2^-) ...	0,006	0,0001	-
Nitrate (NO_3^{2-}) ...	3,6	0,0581	0,25
Sulfate (SO_4^{2-}) ...	192,2	4,002	17,05
Hydrogen Phosphate ($HPO_4 2^-$)	0,007	0,0001	-
Hydrogen Carbonate (HCO_3^-)	248,3	4,07	17,34
Sum :	1491	23,48	100,0

Undissociated Components:		millimol/kg mmol/kg
Silicic acid (meta (H_2SiO_3)	27,6	0,353
Dissolved solid matter, Sum :	1519	

Detectable in traces are:

Free dissolved carbon dioxide (CO_2) in portions no more definitely traceable of less than 5 mg/kg.

Not detectable are:

Ammonium (NH_4^+) (limit of detection 0,05 mg/kg), Manganese (Mn^{2+}) (limit of detection 0,004 mg/kg)
Hydrogen sulphide (HS^-) (limit of detection 0,005 mg/kg)
Hydrogen arsenate (limit of detection 0,0005 mg/kg)

Notes:			
	Solid residue from evaporation at 180°C	1394	mg/kg
	Oxidizability (consumption of KMnO4)	0.4	mg/kg
	Phenoloid substances as total phenoles traces abt.	0,006	mg/kg

Table 7.5 Details of chemical analysis of Khatt thermal water

of Khatt does not seem exceptional, nor is there any unusual development of karstic features in the dominantly limestone strata. From the chemical analysis the water is no different from other ground waters in this part of the study area, and certainly would not be thought of as being derived from some deep-buried mineralised source. The Khatt water seems to be of meteoric origin which has been subject to chemical change during its passage through the ground.

Generally speaking, the temperature of ground water can be assumed to increase with depth at the average geothermal gradient of heat distribution in rock of about $1^{o}C$ per 30 metres. The mountain range to the east of Khatt reaches heights of 1000 m above msl and the pattern of ground water movement probably takes the water on a deep circuitous route before it finally emerges at some 30 m above msl at Khatt. The particular mechanism that causes the springs to issue at this locality is unknown but it is probably a combination of fault controlled solution channels in the limestone in juxtaposition with less permeable older gravels at the mountain front. With a mean air temperature in the mountain region estimated to be about $26^{o}C$ it would require penetration of rainwater to depths of at least 450 m to produce a temperature of $41^{o}C$ $\{26 + (450/30)\}$. It is more likely that the percolating ground water has been heated up to more than $50^{o}C$ in its deep travel path and is cooling before it emerges at the surface at approximately $40^{o}C$ in the Khatt locality.

7.4 CLASSIFICATION OF NATURAL WATERS

Ground water is a complex chemical substance since it is in intimate contact with many rock minerals having a wide range of chemical properties. During the passage of water from the outcrop area to the discharge area it is subjected to a wide range of time, temperature and pressure conditions which tend to increase the mineralisation of the water. The rate of ground water movement vertically through the soil or laterally at greater depths is slow by most standards of water flow. A solution moving through a porous medium where chemical equilibrium has been achieved will behave like a solution moving through an artificial ion-exchange column, whereas if equilibrium has not been attained, then the solution will have a composition that is influenced by both rate of flow and rate of chemical reaction.

In order to study the hydrochemistry of the area, various methods are available for presenting the essential information and these range from numerical to graphical representations. The trilinear plot is one of the graphical methods that seems particularly suited to the study in hand since it allows the individual waters to be classified and at the same time enables an interpretation of the changes within any areal distribution. The particular trilinear diagram chosen is that proposed by Piper (1944) which utilises two triangular fields for plotting percentage milliequivalent per litre (meq/l) values of cations and anions respectively, and a related diamond shaped field for classification and interpretation as shown in Figure 7.7(a). Piper (1953) subdivided the diamond field into nine areas (Fig.7.7(b)); each of which indicates a certain quality type which is described below:-

1: Alkaline earths exceed alkalies

2: Alkalis exceed alkaline earths

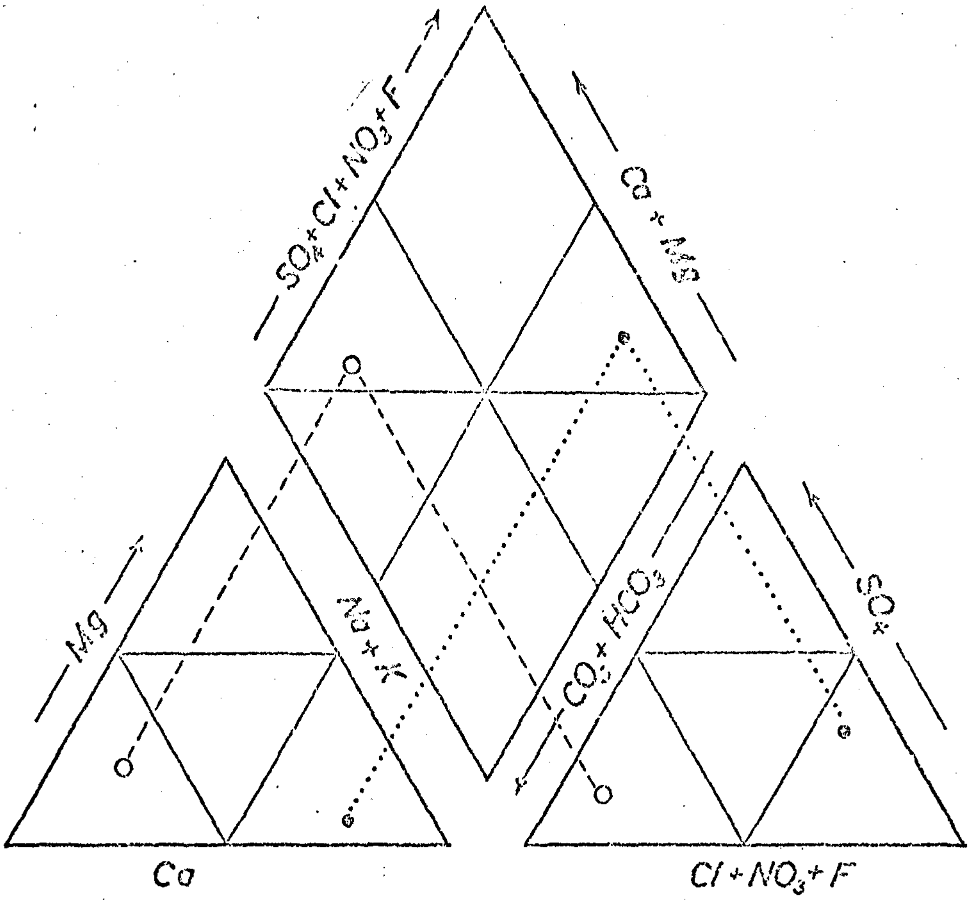
3: Weak acids exceed strong acids

4: Strong acids exceed weak acids

5: Secondary alkalinity exceeds 50%

6: Secondary salinity exceeds 50%

(a)



(b)

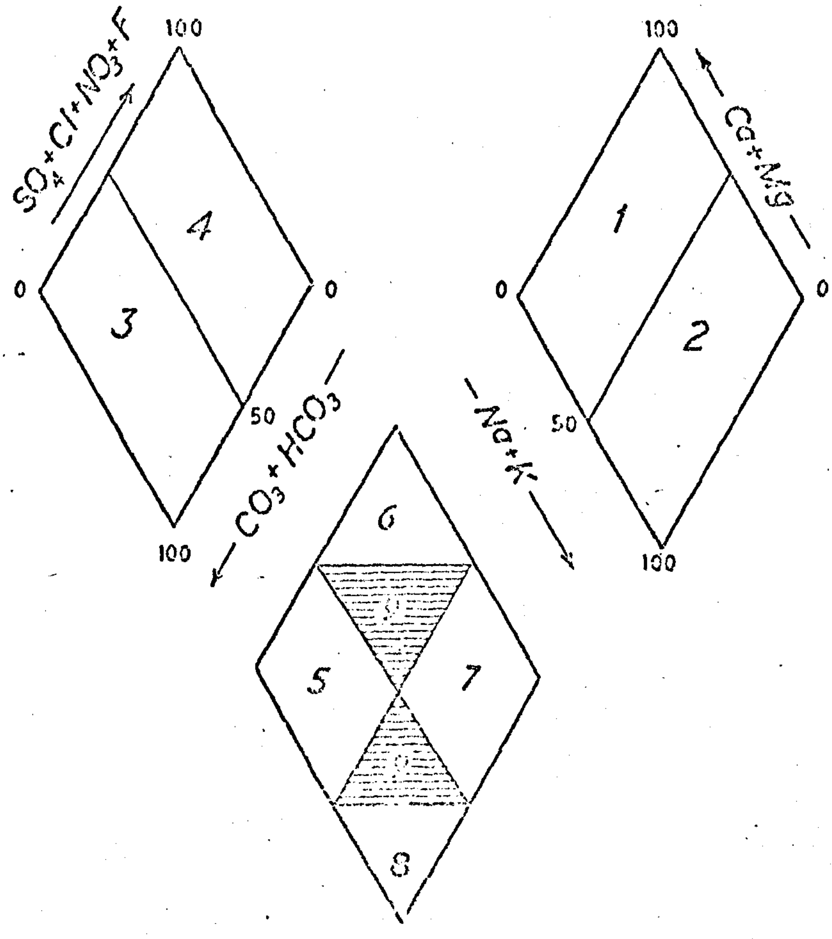


Fig. 7.7 (a) Piper trilinear diagram

(b) Piper classification areas

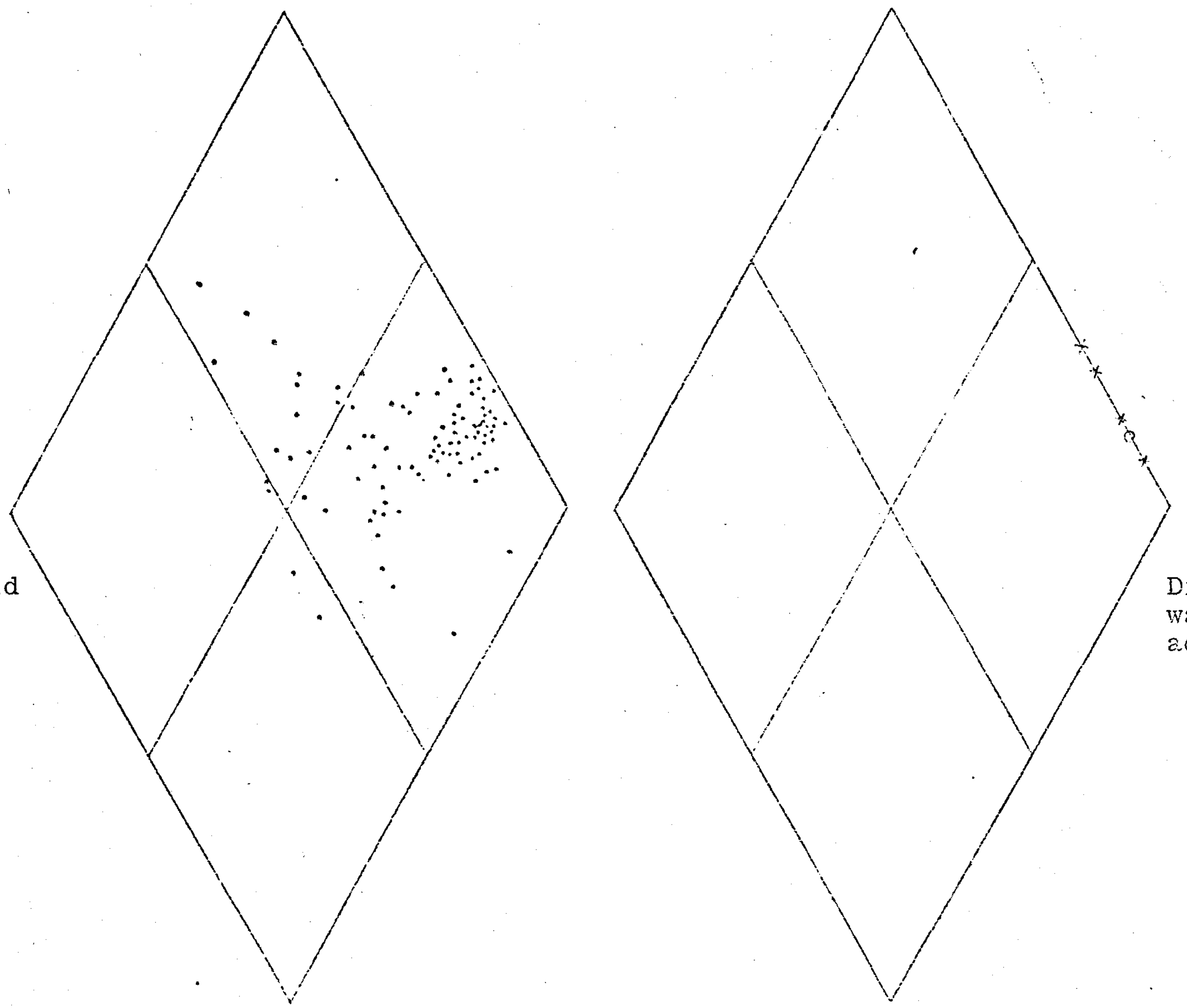


Fig. 7.8(a)

Distribution of ground waters from northern UAE.

(b)

Distribution of sea-water and deep aquifer waters.

7: Primary salinity exceeds 50%

8: Primary alkalinity exceeds 50%

9: None of the groups exceed 50%

When all the waters from the northern UAE are plotted together, they may be seen from Figure 7.8 (a) to fall almost without exception into area 4 of Piper in which the strong acids of SO_4, CL, NO_3 and F exceed the weak carbonate and bicarbonate acids. Also shown in Fig.7.8(b) is a similar plot of the four available 'foreland' waters together with sea water, and the results are closely grouped together in area 7. Considering the four ground water units individually as graphically shown in Figure 7.9 to 7.12, their waters may be classified as follows:-

Ground water unit	Piper area	Dominant cation	process anion
Mountain	4	Mg $\leftrightarrow$ Na	-
Gravel Plain (N)	7	Na	Cl
Gravel Plain (S)	4	Mg $\leftrightarrow$ Na	-
Dune Sands	7	Na	Cl

The triangular cation field shows a distinct trend from magnesium to sodium in two of the units, while the remaining units are sodium dominant. Similarly, in the anion field, two units are chloride dominant with the others having no dominant anion or trend.

Using a slight modification of Piper's trilinear diagram, Back (1961) introduced the concept of hydrochemical facies as a method for the interpretation of regional relations between hydrochemistry, lithology and ground water flow (Fig. 7.13). The resultant facies associated with the ground water units are tabulated below:-

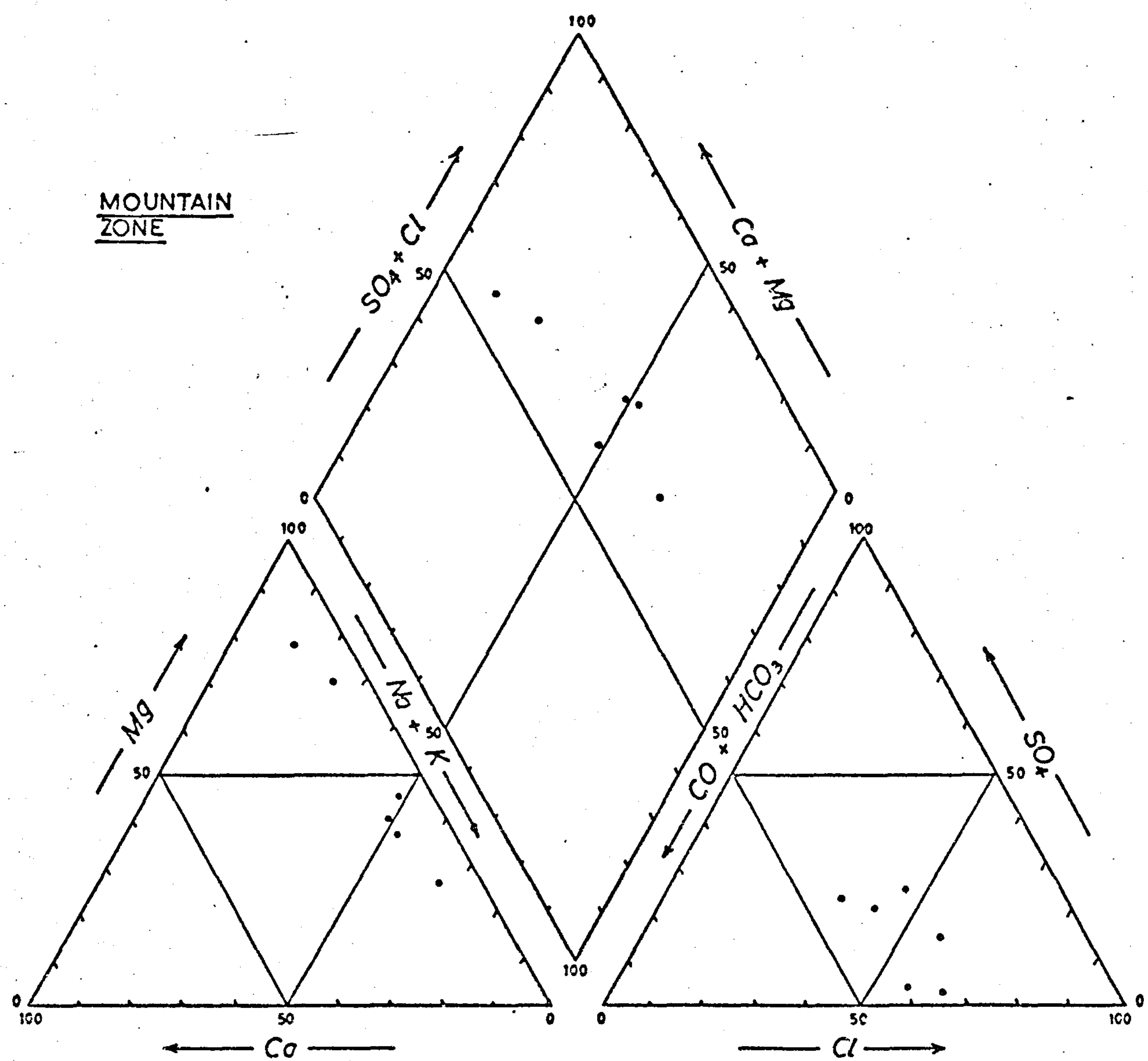


Fig. 7.9 Distribution of ground waters from Mountain unit.

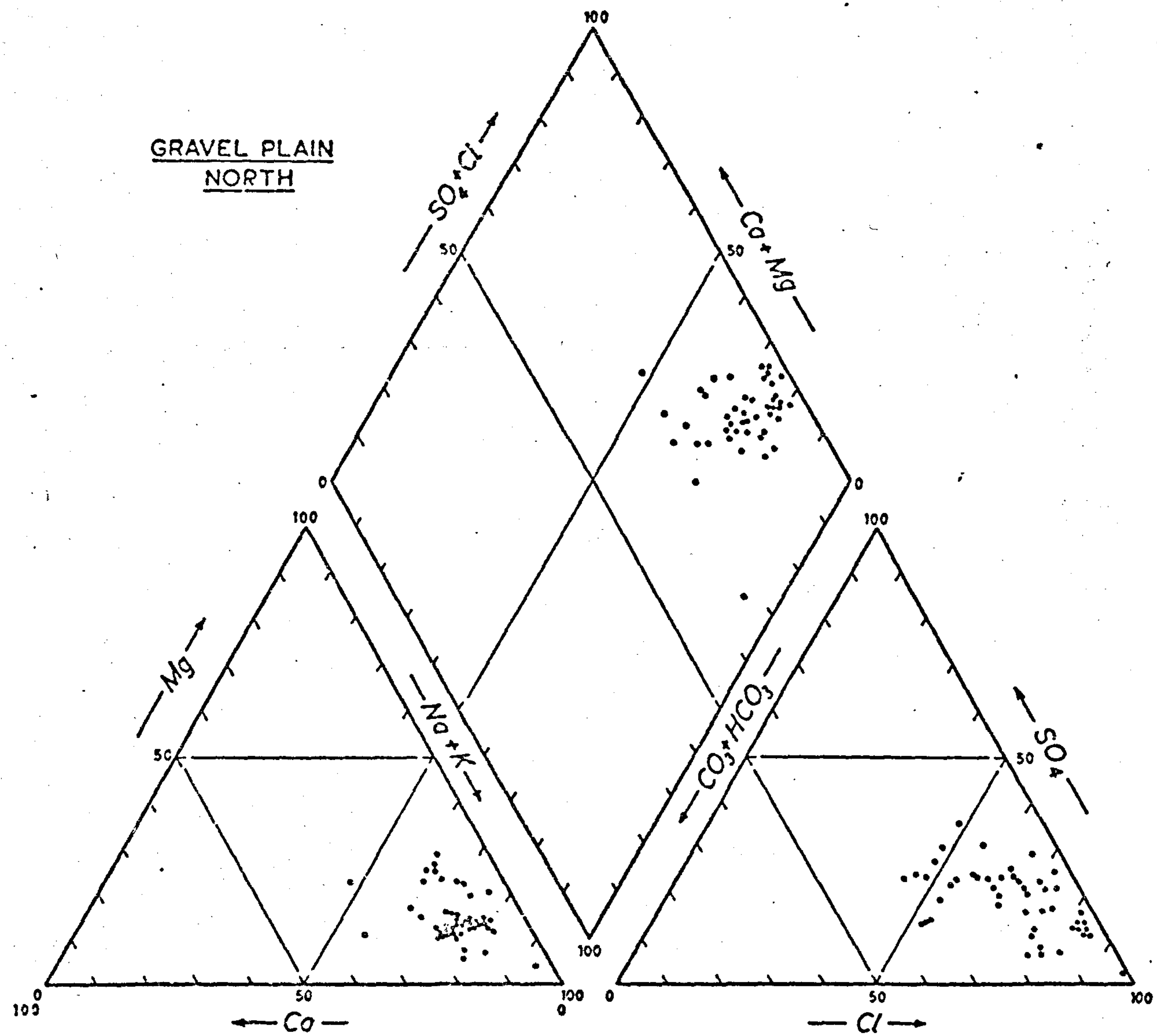


Fig. 7.10 Distribution of ground waters from Gravel Plain (North) unit

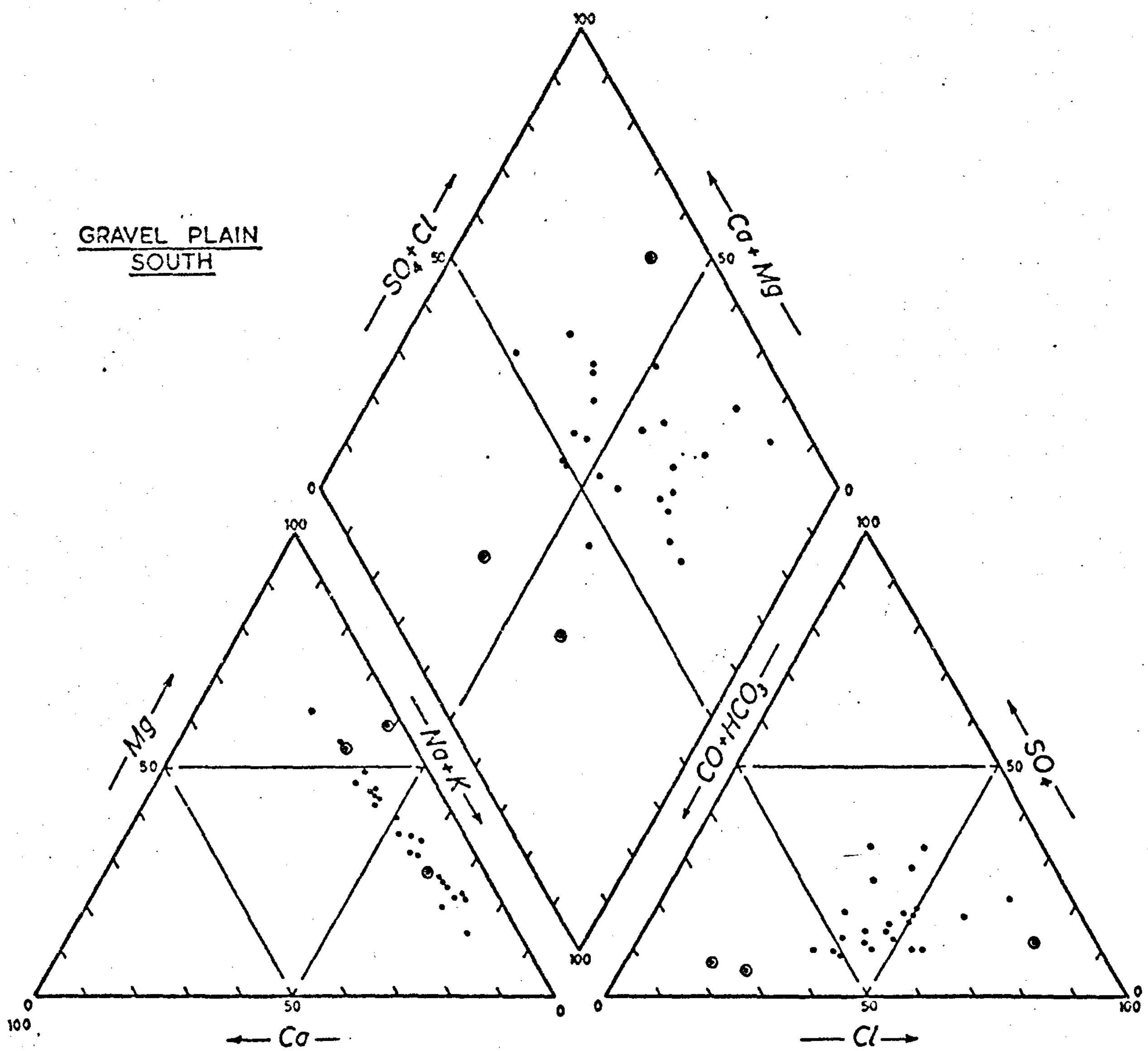


Fig. 7.11 Distribution of ground waters from Gravel Plain (South) unit

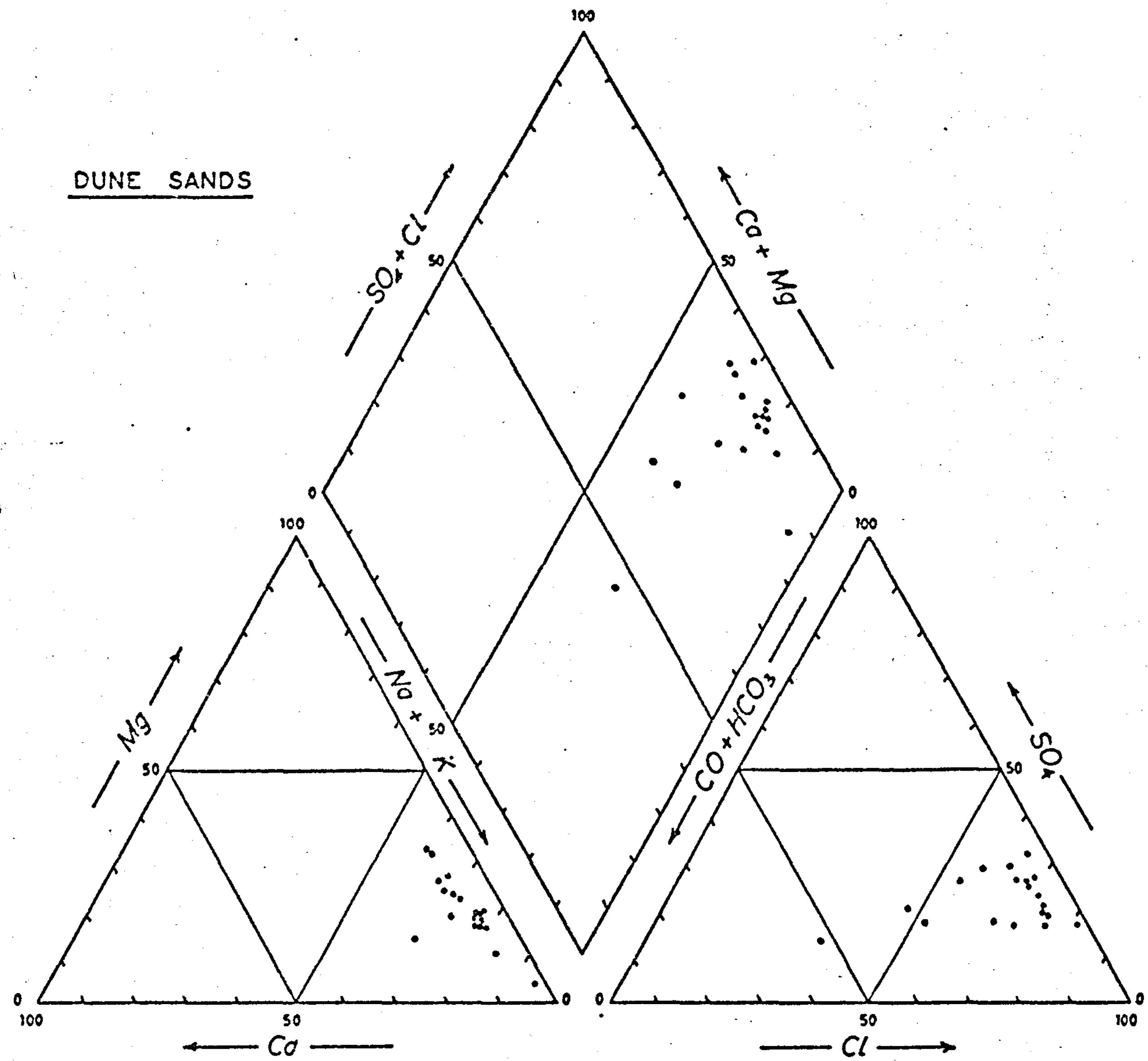


Fig. 7.12 Distribution of ground waters from Dune Sand unit

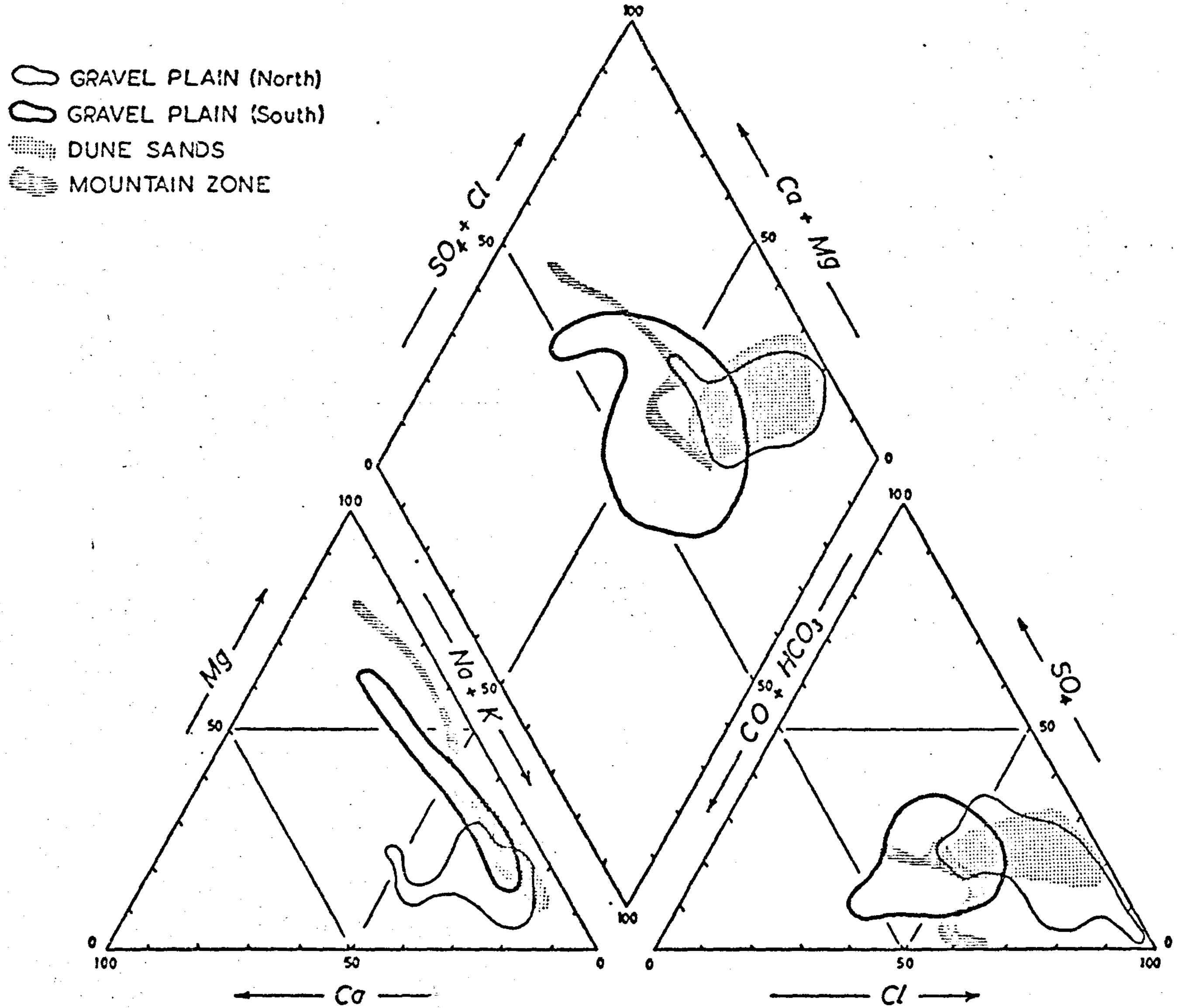


Fig. 7.12 (a) Distribution of ground waters from northern UAE

G.W. Unit	cation facies	anion facies
Mountain	Na-Ca; Ca-Na	$Cl-SO_4-HCO_3$
Gravel Plain (N)	Na-Ca	$Cl-SO_4-HCO_3$
Gravel Plain (S)	Na-Ca; Ca-Na	$Cl-SO_4-HCO_3$
Dune Sands	Na-Ca	$Cl-SO_4-HCO_3$

The genesis of the geochemical character of ground water can be explained from such hydrochemical facies studies, but it is clear that no quantitative conclusions can be drawn without knowledge of the mineralogy and permeability of the rocks and the ground water flow regime operating within them. Various chemical reactions may operate during the passage of water through the ground and Chebotarev (1955) has demonstrated that the changes follow a sequence of the type:-

$$HCO_3 \rightarrow HCO_3 + Cl \rightarrow Cl + HCO_3 \rightarrow Cl + SO_4 \rightarrow Cl$$

with freshly infiltrated ground water changing from a bicarbonate type via a sulphate type to a chloride type where the travel time is sufficient for the sequence to be complete.

The map in Figure 7.14 shows the location of analytical data with respect to three flow lines, and the results of such data are plotted alongside on the basis of hydrochemical facies diagram referred to previously. In the case of two of the flow lines there is a steady change in the direction of flow from a Ca - Na; $Cl - SO_4 - HCO_3$ water through a Na - Ca; $Cl - SO_4 - HCO_3$ water to an end point in the Na - Ca; $Cl - SO_4$ facies. One common feature is the general increase in total mineralisation with the length of the flow path. The third flow line was selected as a continuation of that in the Gravel Plain (South) but demonstrates none of the simplicity of the other two. This is probably because it lies along the route of the Wadi Lamhah from which it may occasionally receive recharge which would interrupt or even reverse some of the chemical reactions.

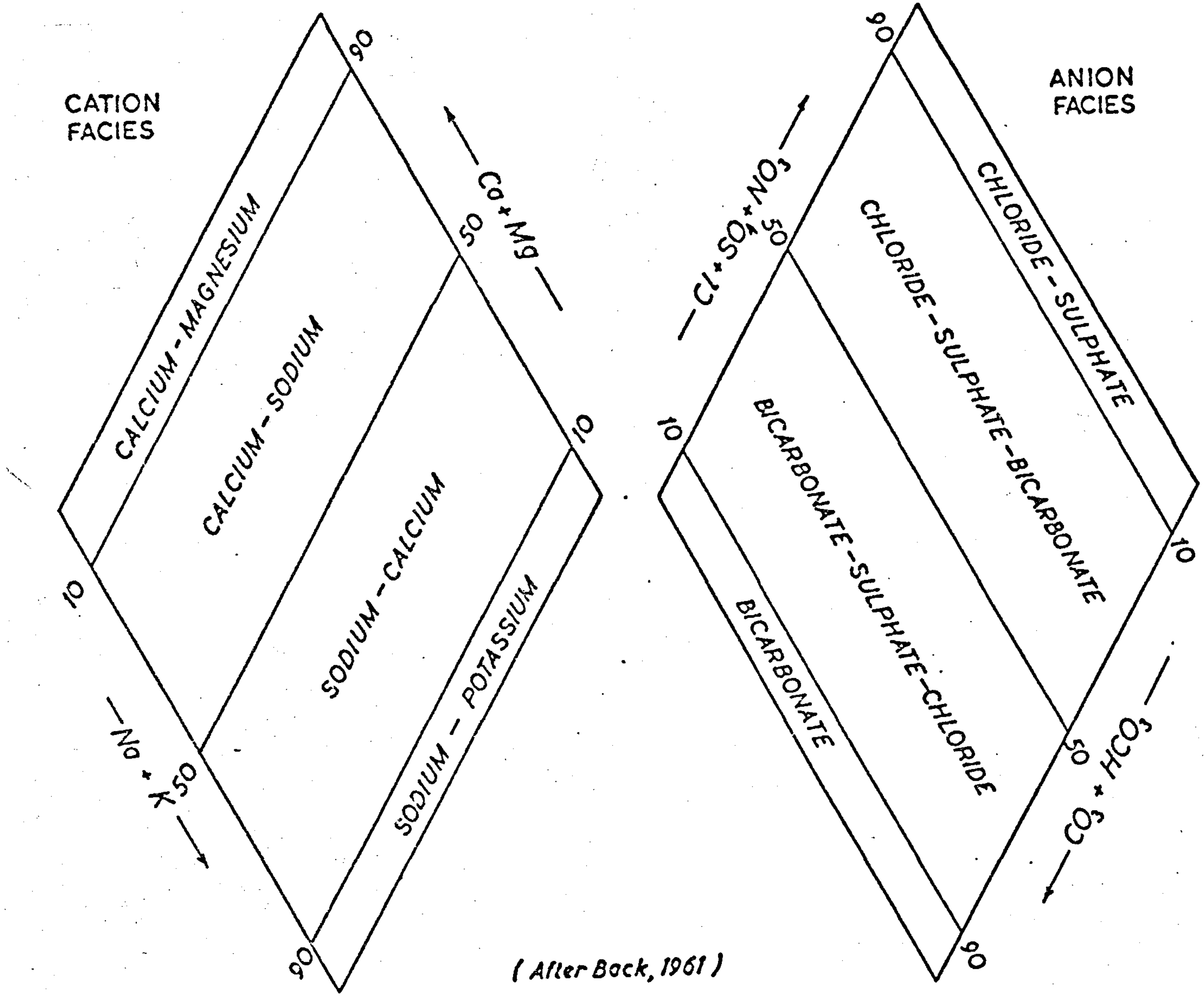


Fig. 7.13 Hydrochemical facies diagram

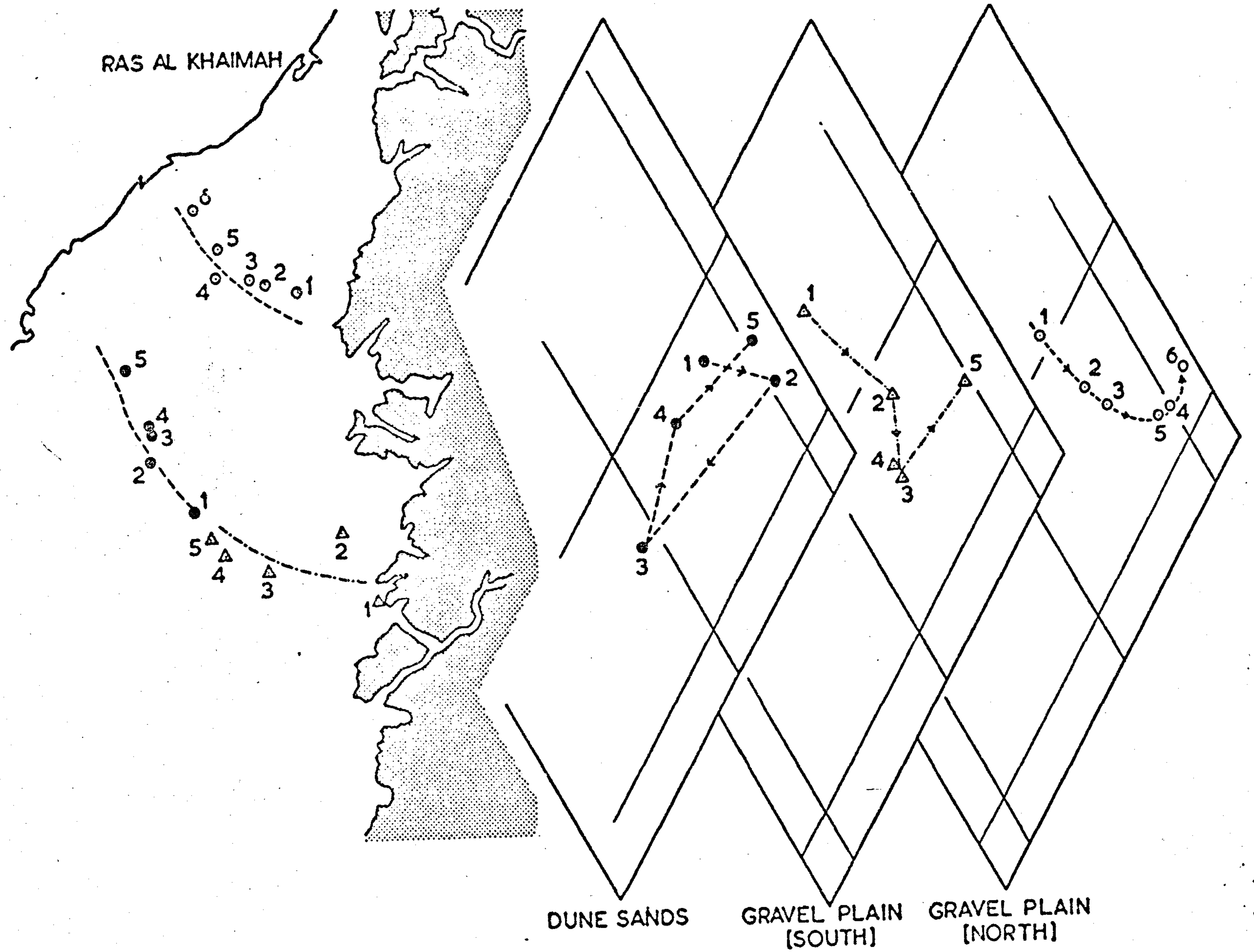


Fig. 7.14 Variation in ground water chemistry along flow lines

One particular feature of the tri-linear plot is that mixtures of two ground waters, assuming that all products remain in solution, will plot as straight lines that join the end points representing the two individual waters. The distinct curvature and nature of the plots indicates that a number of chemical reactions may be involved. For example, the proportion of chloride is increased by the reduction of sulphate, while base exchange with sodium exchanged for magnesium is clearly suggested by the character of the cation field in the tri-linear plot for at least three of the ground water units.

7.5 QUALITY CRITERIA AND USE LIMITATIONS

As the most important of all natural resources, water serves many purposes ranging from internal consumption by living organisms through agricultural and industrial uses to the transport of the wastes of civilisation. These many purposes are known as 'beneficial uses', and in the UAE such major uses are 1) domestic water supply and 2) agricultural water supply (irrigation and livestock). The relative importance of these beneficial uses depends upon the economy of the area and the need of the inhabitants. Each of these uses will be considered in turn.

Domestic Water Supply.

The use of water by human beings for drinking and other domestic purposes is generally accepted as the highest or most essential use of water. Such water therefore must be provided with the highest degree of sanitary protection though some of the other beneficial uses may have water-quality requirements that are more stringent in certain respects than those for drinking water.

> Calcium: The human body requires up to 2 grams of calcium per day, an amount considerably in excess of the calcium concentration of normally consumed quantities of the most hard water. Concentrations of up to 1800 mg/l of calcium in drinking water have been reported to be harmless, though excessive calcium in drinking water has been implicated as a factor predisposing to the formation of concretions in the body such as kidney stones. While several effects of calcium in drinking water and physiological reactions have been suspected,

no definite cause or relationship has as yet been proved. So far as can be determined at the present time, calcium limits are desirable for domestic supplies not because of a hazard to health, but because calcium may be disadvantageous for other household uses, such as washing, bathing, and laundering, and because it produces incrustations on cooking utensils and water heaters.

The USPHS drinking water standards of 1962 and the WHO European Standards of 1961 do not contain any limits for calcium, but the WHO International Standards of 1958 indicate that 75 mg/l of calcium is a permissible limit and 200 mg/l would be an excessive limit in drinking water.

Chlorides: Chlorides are found in practically all natural waters. They may be of natural origin or derived from (a) sea water contamination, (b) from salts spread on fields for agricultural purposes, (c) from human or animal sewage, or (d) industrial effluents. Chlorides in drinking waters are generally not harmful to human beings until high concentrations are reached, although chlorides may be harmful to some people suffering from diseases of the heart or kidneys. Restrictions on chloride concentration in drinking water are generally based on palatable requirements rather than on health. The tolerance of chloride by human beings varies with climate and exertion, and chlorides lost through perspiration may be replaced by chloride in either the diet or drinking water. There are reports from hot dry areas that chloride concentrations of up to 900 mg/l have not been harmful. Chloride limits, both those in use as standards and those recommended as possible standards, vary over a wide range. The USPHS drinking water standards recommend that chlorides should not exceed 250 mg/l although in other agencies and other countries the limiting criteria for chlorides have been given at values ranging from 5 mg/l to 600 mg/l. The WHO International Standards set a permissible limit of 200 mg/l and an excessive limit of 600 mg/l. For the WHO European drinking water standard the recommended limit is 350 mg/l and no tolerance limit is specified.

Dissolved Solids: The USPHS drinking water standards (1962) specify that the total dissolved solids should not exceed 500 mg/l if more suitable supplies are available. This limit was set primarily on the basis of taste thresholds. The WHO International Standards (1958) set the "permissible limit" at 500 mg/l and the "excessive limits" at 1500 mg/l, but no "maximum allowable limit" is given. The WHO European Standards (1961) do not include limits for total dissolved solids. Many communities on a world-wide basis use water containing from 2000 - 4000 mg/l of dissolved solids when no better is available. Such waters are not palatable, may not quench thirst, and may have a laxative action on new users. However, no harmful physiological effects of a permanent nature have been called to the attention of the health authorities. Waters containing more than 4000 mg/l of total salts are generally considered unfit for human use, although in hot climates higher salt concentrations can be tolerated than in temperate climates. It is generally agreed that the salt concentration of good palatable water should not exceed 500 mg/l; however, higher concentration may be consumed without harmful effects. Each water with a total salt concentration of over 1000 mg/l should be judged on the basis of the local situation, alternative supply, and the reactions of the local population.

Fluorides: Fluorides in sufficient quantity are toxic to humans with doses of 250 - 450 mg giving severe symptoms. There are numerous publications describing the effects of fluoride-bearing waters on dental enamel on children and these effects lead to the generalisation that water containing less than 0·9 - 1·0 mg/l of fluoride will seldom cause mottled enamel in children, and for adults concentrations less than 3 or 4 mg/l are not likely to cause endemic fluorosis. Abundant literature is also available describing the advantages of maintaining 0·8 - 1·5 mg/l fluoride in drinking water to aid in the reduction of dental decay, especially among children. It is significant to note that the presence of about 1·0 mg/l of fluoride ion in natural waters may be more beneficial than detrimental. The USPHS drinking water standards (1962) set a limit on fluorides based on annual average daily temperatures and in arid climates comparable to those of the UAE the recommended control limits of fluoride would be between 0·6 - 0·8 mg/l.

Hardness in ground water may be caused by the natural accumulation of salts from geological formations or from return flows from irrigation. The total hardness is usually less than 250 mg/l in good waters and is considered unsuitable for general domestic purposes when it is in excess of 500 mg/l. Detrimental effects of hard water are mainly economic and are related to the extra expense on soap and other cleansing agents. Hard waters have had no demonstrable harmful effects on the health of consumers, and indeed it is 'soft' waters that are generally associated with higher death rates.

Iron: The WHO International Standards (1958) contain a permissible limit of 0·3 mg/l and an excessive limit of 1·0 mg/l, but prescribe no maximum allowable limit, while the WHO European Standards (1961) set a recommended limit of 0·1 mg/l. The limits are not imposed for physiological reasons since all human beings require iron in their diet. It is for reasons of taste and aesthetics that the amount of iron is restricted so as to avoid staining on clothes and porcelain as well as the distinctive unpalatable taste.

Magnesium is an essential mineral element for human beings, but at high levels imparts an unpleasant taste and has a laxative effect. The WHO International Standards (1958) have a permissible limit of 50 mg/l and an excessive limit of 150 mg/l, but no maximum allowable concentration. The WHO European Standards (1961) have a recommended limit of 125 mg/l, though if sulphate exceeds 250 mg/l then the magnesium is limited to 30 mg/l. The taste threshold can be as low as 100 mg/l, but is more commonly at about 500 mg/l.

Nitrate when present in significant quantities in ground waters is usually attributed to pollution from human and animal faecal wastes or the downward leaching of excess fertiliser. The WHO International Standards (1958) has no limit, though their European Standards (1961) has a recommended limit of 50 mg/l. The limit has been established because of the relationship between high nitrates in water and infant methemoglobinemia, the so-called 'blue baby' disease. Excess nitrates in adults can cause irritation of the gastro-intestinal tract and bladder.

Potassium resembles sodium in many of its properties, and although an essential nutritional element, will act as a cathartic when present in large quantities. No limiting standards are set for this element, though about 1000 mg/l would probably be regarded as the extreme limit for drinking water.

Sodium salts are extremely soluble in water, and are said to be harmful to persons suffering from cardiac and renal diseases. No limiting standards have been officially set; though Schoeller (1937) has advocated a limit of 100 mg/l, while Hibbard (1934) recommended a limit of 10 mg/l as desirable.

Sulphate can occur naturally in ground waters particularly when associated with gypsiferous deposits, but may also be associated with various forms of pollution. The WHO International Standards (1958) established a permissible limit of 200 mg/l and an excessive limit of 400 mg/l, but set no maximum allowable limit. Their European Standards (1961), like those of the USPHS (1962) recommend that sulphates should not exceed 250 mg/l, though the limits appear to be capable of relaxation without harmful effects. Thus consumers of water containing up to 500 mg/l have suffered no ill effects other than a laxative action on new users.

The ground water in the study area is far from universally suitable for drinking purposes, though much variation is present. The amounts of dissolved matter are very high, indeed average values are higher in all ground water units than the WHO permissible limits of 500 mg/l. The better quality water is in the Mountain and Gravel Plain (South) units with the least mineralised water being that of Masafi with 262 mg/l. The values in the Gravel Plain (North) and Dune Sands units tend to range upwards from 1500 mg/l to an exceptional 10,000 mg/l. Values for calcium greater than the WHO excessive limits are found at Rahaba (523), Kuways (355), Bida (256), Uraybi (255), Haremle (228) and Ma'yarid (212), all restricted to the Gravel Plain (North) unit, with another twenty samples having values greater than the WHO permissible limit of 75 mg/l. The same borehole waters, together with those of Biyalan (220), Shimnal (203), Hudaybah (188) and Bidiyah (153) in the Gravel Plain (North) and Qaran (376), Adhieb (255), Rashid (210), in the Dune Sand unit have values of magnesium greater than the WHO excessive limit of 150 mg/l. Furthermore, three-quarters of all waters sampled from the Gravel Plain (North) and Dune Sand units have sulphate in excess of 250 mg/l with magnesium greater than the limit of 30 mg/l. Every water sampled from the Gravel Plain (North) and Dune Sand unit without exception has sodium values well in excess of Schoeller's suggested limit of 100 mg/l, and not a few show similarly high values in both other units. Sulphate is lower than the recommended limit of 250 mg/l in all samples from the Gravel Plain (South) and Mountain units, but is higher in the majority of waters from the other units. This same pattern also holds for chloride with the excessive limit set at 600 mg/l, and many waters with more than double that limit. Fluoride values are nearly all well below any critical level, as with only few exceptions are the values of iron. All nitrate values are safely less than the limit of 50 mg/l, with the exception of Qaran (230), Rahaba (97) and Hamraniyah (86) where the water is unsuitable for drinking purposes.

Agricultural Water Supply

Water required on farms for purposes other than domestic, can usually be categorised as either that consumed by livestock or that used for irrigation.

Livestock: The permissible concentrations of substances in water for livestock depends on the water consumption of the animals involved. These will vary with the temperature and humidity, the water content of the diet and the salinity of the water. Generally speaking, water used for stock is subject to similar quality limitations as those relating to the drinking water of human beings. What is different is that animals can tolerate higher salinities than humans as well as higher values of specific substances. However, highly mineralised water will cause physiological disturbances which can affect lactation and reproduction so that milk and egg production may be reduced if not terminated. There is little in the published literature on permissible or allowable limits for livestock consumption. A maximum permissible limit of 2500 mg/l TDS has been suggested, but this is very much less than the information issued by the Government of Western Australia (1950) which gives safe upper limits as:-

	mg/l
poultry	2860
horses	6435
dairy cattle	7150
sheep	12900

McKee and Wolf (1963) have collated information from various sources on the limits for individual substances and they are summarised below for those elements normally present in water analyses:-

	mg/l		mg/l
Ca	1000	SO_4	1000
Mg	5000	Cl	1500
Na	2000	NO_3	2000
		F	1

It is evident that most waters available in the northern UAE are suitable for purposes of livestock watering.

Irrigation: Several criteria are generally used to determine the suitability of water for irrigation and among those commonly referred to are:-

1) residual sodium carbonate (RSC)
2) presence of specific minor or trace elements
3) salinity, expressed either as TDS or EC
4) sodium adsorption ratio (SAR)

If much of the Ca and Mg in the water were to be precipitated, the residual water could be considerably higher in sodium which in combination with bicarbonate might lead to the production of alkali efflorescences. The classification of the US Salinity Laboratory (1954) for residual sodium carbonate is:-

$> 2\cdot5$	meq/l	RSC :	unsafe
$1\cdot25$ to $2\cdot5$	meq/l	RSC :	marginal
$<1\cdot25$	meq/l	RSC :	safe

On this basis, from nearly one hundred analyses examined from the UAE and summarised in Tables 7.6 to 7.9, the great majority have negative or nil values and relatively few (four) are unsuitable in this regard for irrigation. The waters that indicate some potential hazard are from T. Rashid (19·12),

	Salinity EC	CO_3 + HCO_3	Ca + Mg	RSC	Na	$\frac{Ca + Mg}{2}$	SAR	Toxic Elemt.	Irrig. Class
47	372	1.98	3.79	neg.	0.48	1.38	0.35		C_2S_1
116	1330	4.26	6.85	neg.	6.53	1.85	3.53		C_3S_1
51	1410	5.06	8.40	neg.	8.87	2.05	4.33		C_3S_1
33	439	1.90	2.99	neg.	2.65	1.22	2.17		C_2S_1
34	490	1.07	2.06	neg.	3.92	1.02	3.84		C_2S_1
118	-	-	0.88	-	5.39	-	-		-
52	366	1.67	3.36	neg.	1.00	1.30	0.77		

Table 7.6 Criteria on suitability for irrigation of ground waters from Mountain unit.

	Salinity EC	CO_3 + HCO_3	Ca + Mg	RSC	Na	$\frac{Ca + Mg}{2}$	SAR	Toxic Elemt.	Irrig. Class
109	1263	4.78	4.04	0.98	8.27	4.01	2.06		C_3S_1
30	1064	4.39	4.87	neg.	8.87	1.56	5.69		C_3S_1
138	1463	5.49	4.75	1.48	9.14	1.54	5.94		C_3S_2
6	1900	5.55	14.92	neg.	9.20	2.73	3.37		C_3S_1
5	560	7.64	4.40	6.48	5.63	1.48	3.80		C_2S_1
25	525	3.13	4.76	neg.	2.26	1.54	1.47		C_2S_1
93	1396	4.10	4.52	neg.	6.96	1.62	4.30		C_3S_1
7									
8	700	8.62	4.72	7.80	7.6	1.54	4.49		C_2S_1
54	419	2.64	4.06	neg.	1.0	1.43	0.70		
91									
106	1463	5.49	7.82	neg.	7.61	1.98	3.84		C_2S_1
151	1224	5.10	3.64	2.92	7.61	1.35	5.64		C_3S_2
H 9	1000	3.40	6.10	neg.	3.70	1.75	2.11		C_3S_1
H10	850	3.60	4.70	neg.	3.70	1.45	2.40		C_3S_1
56	800	2.68	5.38	neg.	2.33	1.64	1.42		C_3S_1
75	660	3.17	3.45	neg.	2.68	1.31	2.05		C_2S_1
78	860	3.34	4.85	neg.	3.45	1.56	2.21		C_3S_1
80	680	3.43	3.78	neg.	2.00	1.37	2.10		C_2S_1
82	750	3.29	4.18	neg.	3.08	1.45	2.12		C_3S_1
85	900	4.03	4.25	neg.	4.50	1.46	3.08		C_3S_1
88	2000	4.63	5.83	neg.	13.40	1.71	7.84		C_3S_2
123	1200	4.07	5.35	neg.	6.45	1.64	3.93		C_3S_1
162	900	3.16	5.58	neg.	3.45	1.67	2.07		C_3S_1
TW2	760	4.50	3.35	2.30	4.33	1.29	3.36		C_3S_1
TW3	1060	4.02	2.38	3.28	7.00	1.09	6.42		C_3S_2
A 2	1140	4.50	3.03	2.94	7.75	1.23	6.30		C_3S_2

Table 7.7 Criteria on suitability for irrigation of ground waters from Gravel Plain (South) unit.

	Salinity EC	CO_3 + HCO_3	Ca + Mg	RSC	Na	$\frac{Ca + Mg}{2}$	SAR	Toxic. Elemt.	Irrig. Class
127	6780		15.93	neg <0	59.81	2.82	21.21		C_4S_4x
146	2394		3.85	neg <0	16.75	1.39	12.05		C_4S_3x
181	1995		5.69	neg <0	15.01	1.69	8.88		C_3S_2
Bur	2100		6.00	neg <0	17.39	1.73	10.05		C_3S_3
Bur	2320		6.27	neg <0	18.05	1.77	10.20		C_4S_3
112	3458		6.97	neg <0	15.66	1.87	8.37		C_4S_3
114	2261		13.54	neg <0	16.75	2.60	6.44		C_4S_2
113	2593		12.75	neg <0	11.31	2.52	4.49		C_4S_2
115	1795		6.68	neg <0	10.88	1.83	5.95		C_3S_2
184	13000		32.76	neg <0	123.76	4.05	30.56		C_4S_4x
Sha'am	C1500		6.43	neg <0	11.74	1.79	6.56		C_3S_2
Sha'am	C1500		6.38	neg <0	10.44	1.79	5.83		C_3S_2
Rahaba	>12000		46.30	neg <0	139.2	4.81	28.94		C_3S_2
23	1064		5.64	neg <0	8.83	1.68	5.26		C_4S_4
97	4256		7.64	neg <0	32.63	1.95	16.73		C_3S_1
85	5748		12.85	neg <0	43.28	2.53	17.11		C_4S_4
96	3724		10.32	neg <0	26.54	2.27	11.69		C_4S_4x
119	9510		24.68	neg <0	85.04	3.51	24.23		C_4S_3
29	1995		8.39	neg <0	19.18	2.05	9.36		C_4S_4x
45	8645		26.51	neg <0	94.22	3.64	25.88		C_3S_2
40	6650		26.25	neg <0	82.13	3.62	22.69		C_4S_4x
42	6517		20.73	neg <0	64.38	3.22	19.99		C_4S_4x
44	9310		34.72	neg <0	90.22	4.17	21.64		C_4S_4x
36	3458		10.56	neg <0	34.80	2.30	15.13		C_4S_4
43	1995		7.19	neg <0	19.31	1.90	10.16		C_3S_3
133	3059		9.58	neg <0	22.79	2.19	10.41		C_4S_3
134	2527		2.44	19.12	28.23	1.11	25.43		C_4S_4

Table 7.8 Criteria on suitability for irrigation of ground waters from Gravel Plain (North) unit.

	Salinity EC	CO_3 + HCO_3	Ca + Mg	RSC	Na	$\frac{Ca + Mg}{2}$	SAR	Toxic Elemt.	Irrig. Class
99	2328			-4.68<0		2.2	6.13		C_4S_2
173	8113			-24.36<0		3.71	16.26		C_4S_4 x
177	6251			-4.58<0		2.26	22.58		C_4+S_4x
89	6786			-10.08<0		2.71	18.54		C_4 S_4x
110	3378			-4.98<0		2.04	12.48		C_4 S_3
87	7847			-16.11<0		3.25	20.88		C_4 S_4x
104	3258			-2.59<0		1.91	11.39		C_4 S_3
176	2050			-0.60<0		1.77	6.50		C_3S_2
90	5686			-7.20<0		2.44	16.49		C_4 S_4x
88	5586			-7.65<0		3.50	11.62		C_4 S_4x
103	10773			-30.34<0		4.44	16.75		C_4 S_4x
164	1662			-2.10<0		1.66	7.84		C_3 S_2
185	2022			-0.90<0		1.61	4.60		C_3 S_2
179	7448			-6.03<0		2.51	9.06		C_4 S_3x
182	6650			13.22		1.43	44.78		C_4 S_4x
64	4041			-7.62<0		2.41	11.55		C_4 S_3
105	6384			-8.44<0		2.63	18.84		C_4 S_4x
101	5686			-8.85<0		2.58	15.34		C_4 S_4x
2	950			3.7		1.33	4.90		C_3 S_1

Table 7.9 Criteria on suitability for irrigation of ground waters from Dune Sand unit.

Riqa Hamra (13·22) and Lamhah (3·7).

Certain specific constituents are undesirable in irrigation water as being potentially harmful to crops. One such critical element is boron to which various plants have differing tolerances. Thus citrus fruits are sensitive, grain crops, tomatoes and potatoes are semi tolerant, and other vegetables are tolerant. A rating table has been prepared by the US Department of Agriculture for crops of various sensitivity and the percentage of water samples from the UAE that fall into the respective grades for sensitive crops are shown in the tabulation.

Grade	UAE %	Sensitive (mg/l)	Semi tolerant (mg/l)	tolerant (mg/l)
Excellent	61	<0·33	<0·67	<1·0
Good	26	0·33 - 0·67	0·67 - 1·33	1·00 - 2·00
Permissible	7	0·67 - 1·00	1·33 - 2·00	2·00 - 3·00
Doubtful	6	1·00 - 1·25	2·00 - 2·50	3·00 - 3·75
Unsuitable	nil	>1·25	>2·50	>3·75

The great majority of UAE samples fall into the excellent or good grade and six percent would be regarded as doubtful and those only for the most sensitive of crops.

Salinity limits for irrigation water depend on the tolerances of the crops on which it is to be used, and these generally have tolerances towards salinity comparable to their tolerances to boron.

A diagram in wide usage for the evaluation of irrigation waters is that devised by the US Salinity Laboratory (1954) which combines total salinity expressed as EC with the sodium adsorption ratio (SAR) defined as $Na/(Ca+Mg/2)^{\frac{1}{2}}$. This results in sixteen different classes (Fig.7.15) which can be used to express the risk of salinity problems and undesirable ion-exchange effects. The classifications of waters analysed are given in Tables 7.6 to 7.9 and Figs. 7.16 and 7.17 for the four ground water units, and in Figure 7.18 for

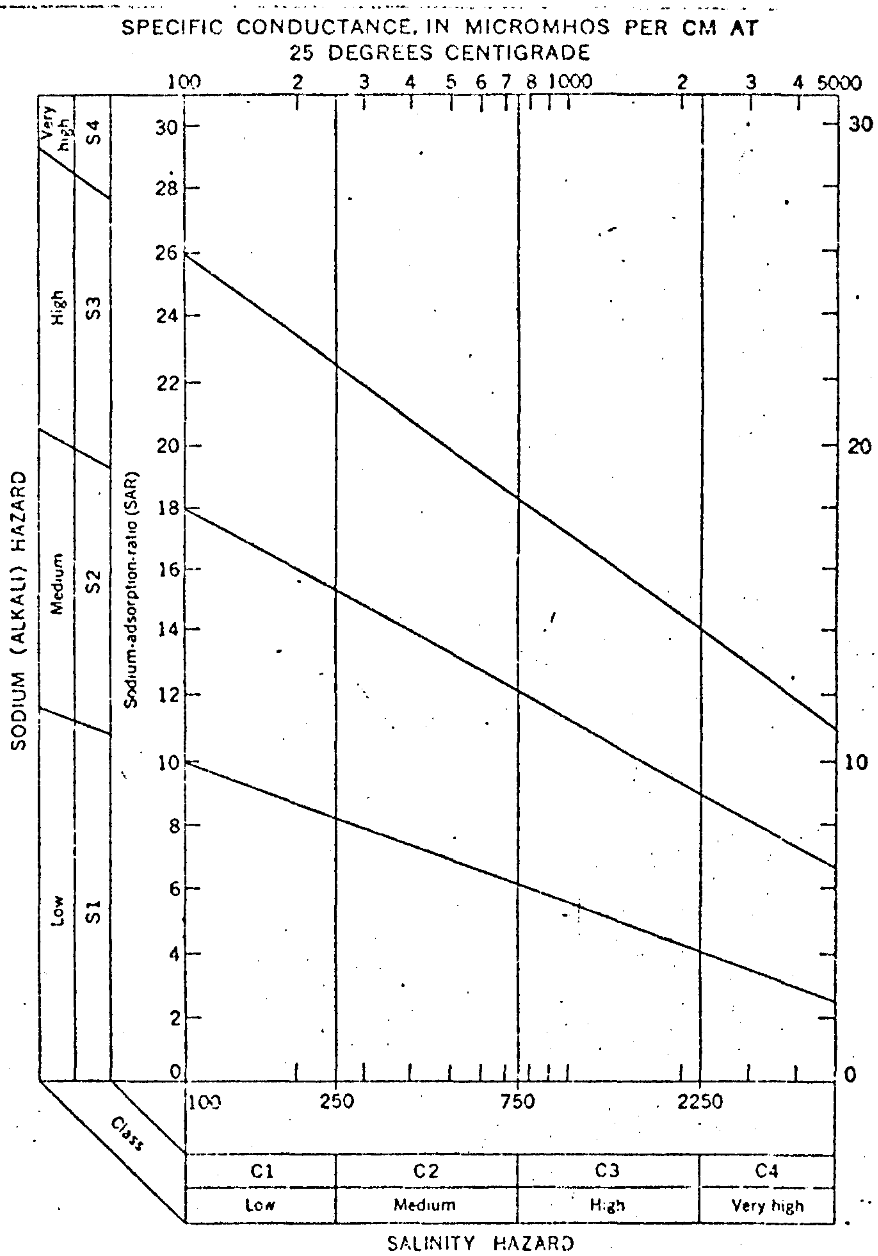


Fig. 7.15 Classification of irrigation waters (after US Salinity Laboratory)

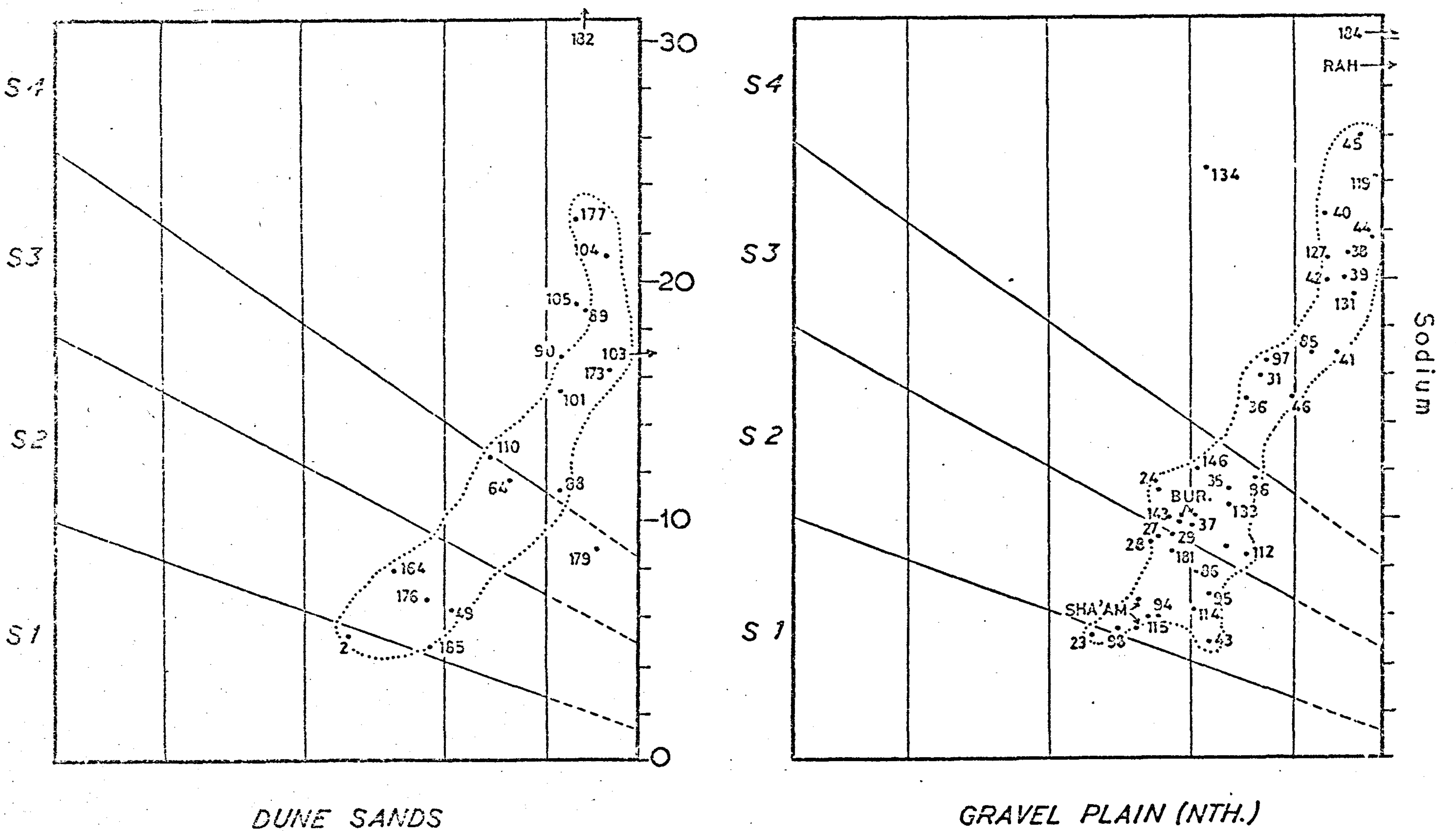


Fig. 7.1 6 Suitability of ground water for irrigation use

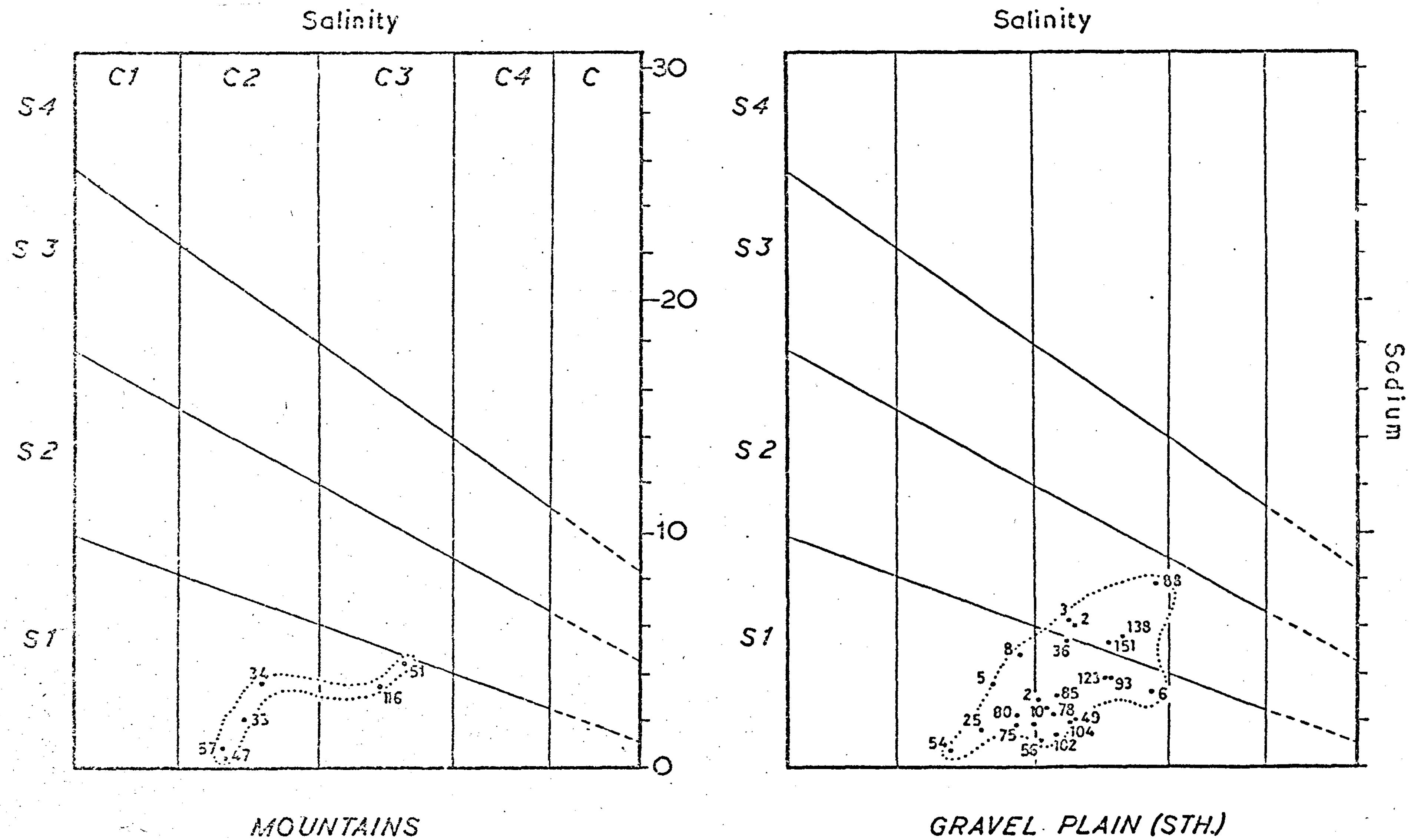


Fig. 7.17 Suitability of ground water for irrigation use

all the samples. Waters from the Gravel Plain (South) and Mountain units range from C_2S_1 to C_3S_1 and would be regarded as suitable, whereas waters from the Gravel Plain (North) and Dune Sand units range from as acceptable C_3S_2 via C_4S_3 off scale to a new class that requires extension of the diagram and could be defined as C_5S_5 with excessively high salinity and sodium hazard potentials.

Strictly speaking the suitability of water for irrigation should be assessed by reference to the particular soils to be irrigated. The same water may be adequate for irrigation on a light, well-drained soil but quite unsuitable if applied to a heavy clayey soil with poor drainage properties. Sodium tends to present a hazard to soils with a medium to high clay content since it is liable to be adsorbed onto the clay minerals. Because the agriculturally important soils in the northern UAE are developed on sands and gravels, the sodium hazard is less than it might be elsewhere. The excessively high salinity of many of the waters will restrict the cultivation of citrus fruit, but the medium to high values would be less of a problem if enough water is supplied for downward leaching and if the irrigation system chosen can avoid damage to foliage. In short, knowledge of a variety of local conditions, both hydrogeological and agricultural, is necessary before categorising of the water with regard to its use.

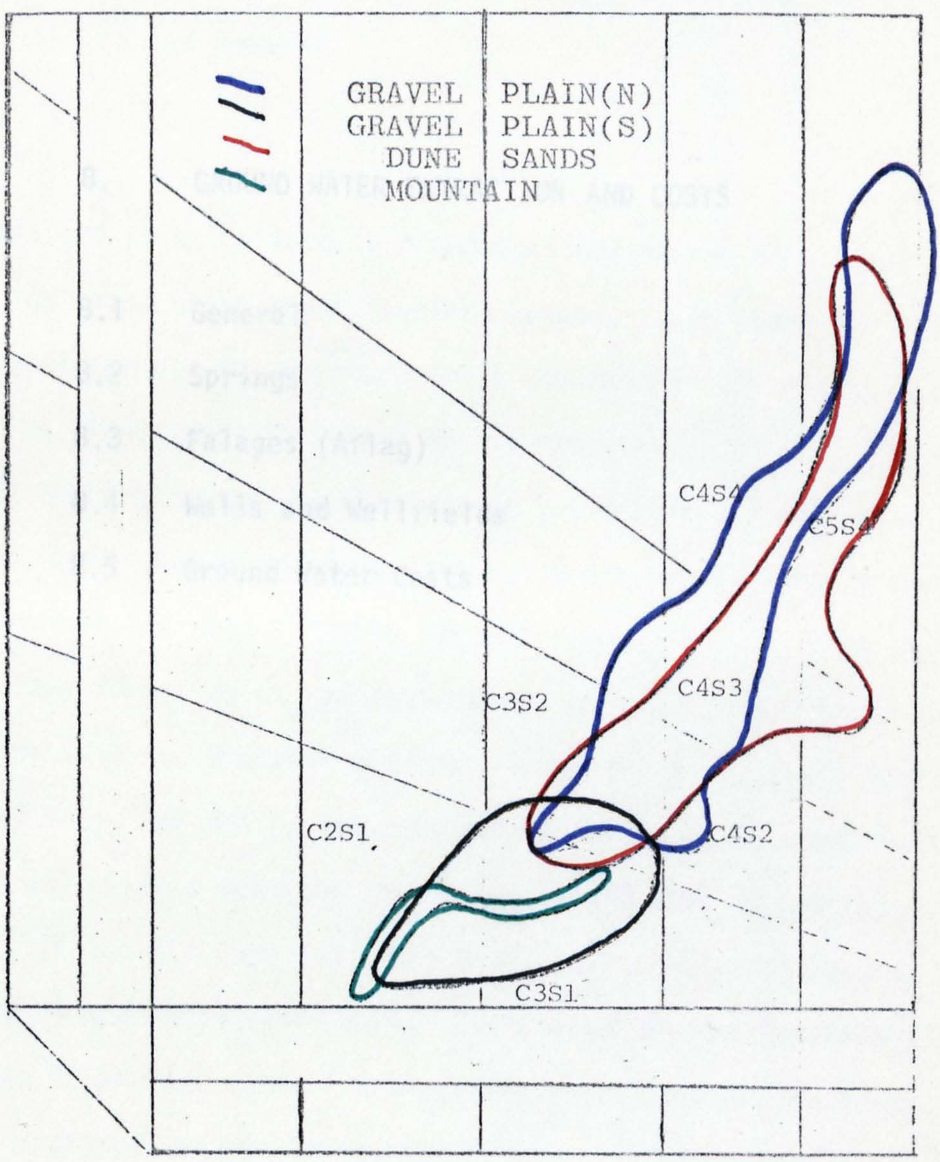


Fig. 7.18 Distribution of all ground waters from study area

8. GROUND WATER EXTRACTION AND COSTS

8.1 General

8.2 Springs

8.3 Falages (Aflag)

8.4 Wells and Wellfields

8.5 Ground Water Costs

8. GROUND WATER EXTRACTION

8.1 GENERAL

Given the arid and semi-arid conditions of the UAE it is not surprising that historically, ground water has been the only water resource available for development. Before the advent of the mechanical pump, sources of ground water would have been restricted to springs and artificial works such as shafts and tunnels.

8.2 SPRINGS

If springs are to be defined in a conventional manner as natural issues of ground water above ground surface levels, then there are few perennial natural springs in the study area; certainly none of any size considered to be significant for water supply purposes.

The Khatt 'springs', to which reference has previously been made with regard to their quality and temperature, are nowadays largely the result of excavation but were formerly natural issues of water from the Musandam Limestone formation at the foot of the steep mountain range (Fig.8.1). Flow from the two main sources, Khatt North and Khatt South (Photo. 8.1 and 8.2), is led to adjacent gardens where it is supplemented for irrigation use of date palms by shallow wells and smaller springs. The central spring (Photo. 8.3. and 8.4) has been considerably enlarged in recent years to form a substantial pool. Because of the scale of modifications undertaken to provide control and gravity distribution structures, as well as the constant use for irrigation, true rest water levels and natural spring discharges are difficult if not impossible to obtain. A relatively uniform baseflow of about 44 litres per second was reported by SWH in 1969 though there are reasons to believe that this discharge is on the high side and that seasonal flows vary significantly. Such com-

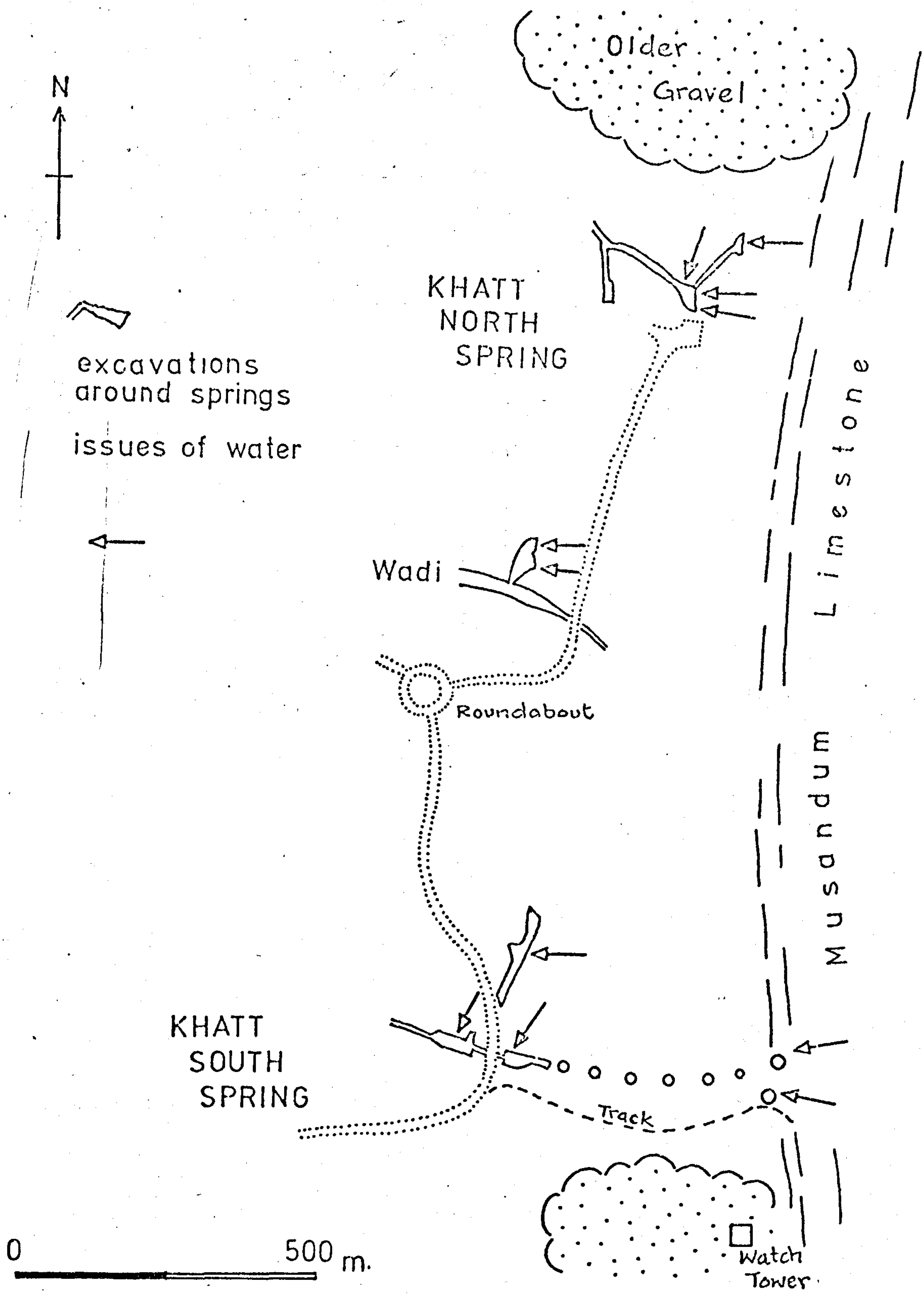


Fig. 8.1 Spring sources at Khatt

Photo. 8.1: Khatt North spring

Photo 8.2: Khatt South spring

Photo. 8.3: Central spring at Khatt after enlargement.

Photo. 8.4: Central spring at Khatt; note steep natural dip of strata.

parative discharge measurements as have been made are tabulated below:

	Feb. 1966	Nov. 1975
north	7·4 l/sec	5·5 l/sec
central	-	3·8 l/sec
south	53·0 l/sec	4·0 l/sec
Totals	60·4 l/sec	13·3 l/sec

Bearing in mind that they were made at the end of the 'wet' season and 'dry' season respectively, the measurements tend to suggest that the 'baseflow' may not be as high as previously reported. Fig. 8.1 indicates that more complicated modifications have been undertaken at Khatt South and these are considered in the next section.

As part of a commercial excercise in the selling of a particular brand of bottled table water, television and newspaper advertisements in the UAE lay considerable emphasis on the Masafi Springs, though the water is actually derived from boreholes adjacent to the bottling plant. The Ain Masafi spring is a small source that has a flow ranging seasonally from 10 to less than 5 l/sec of very good quality water that has been collected and channelled so as to irrigate nearby gardens. Like the Khatt springs, Ain Masafi probably owes its occurrence to a combination of intake area, connected fractures and favourable topography.

8.3 FALAGES (AFLAG)

A 'falaj' is the term used in the UAE to describe the open channels or tunnels that are similar if not identical to the better known qanats or kanats of Iran. Such falages are more common in those parts of the UAE and particularly Oman to the south of the present study area, but

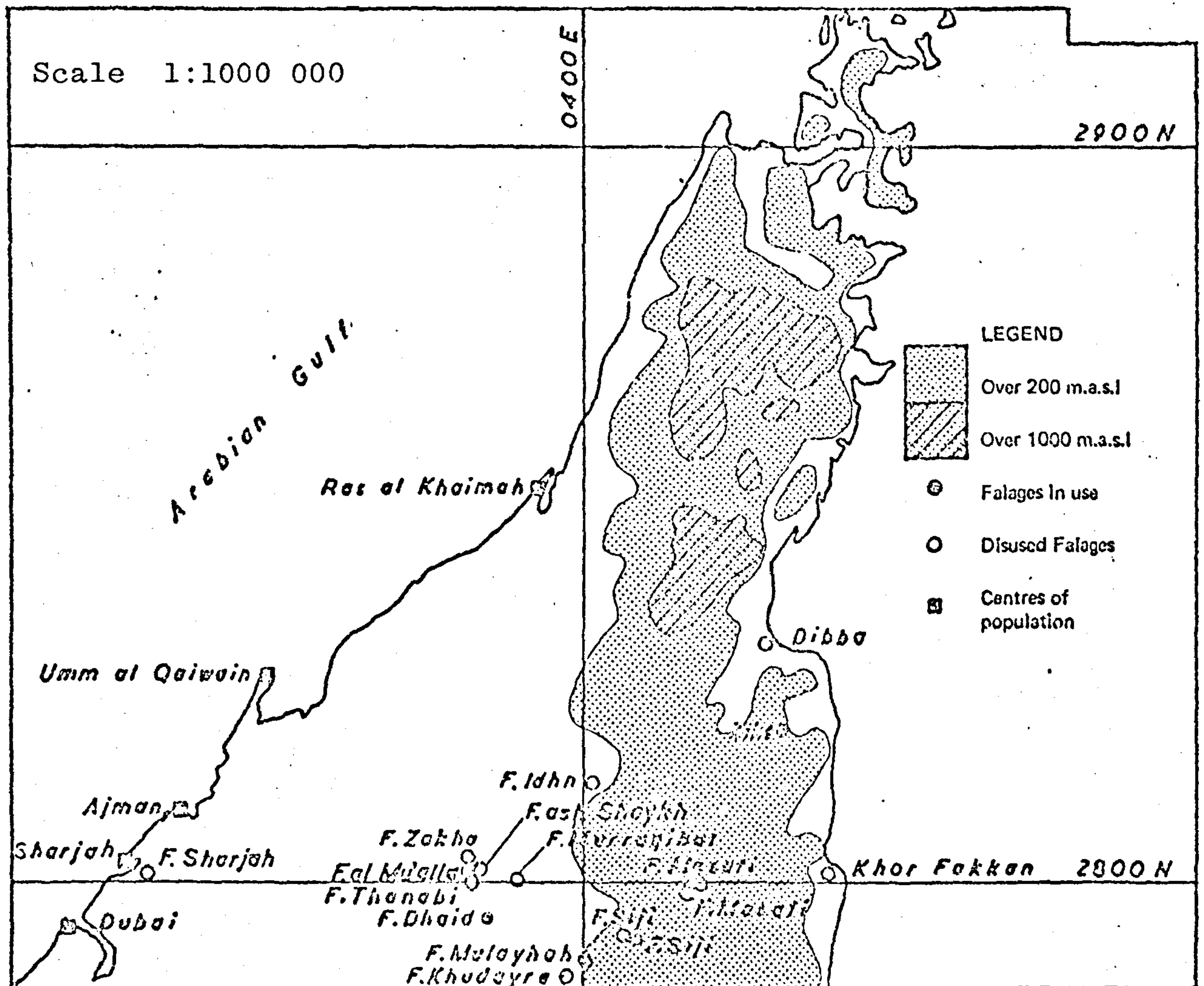


Fig. 8.2 Distribution of falages in northern UAE (after SWH).

a few are found in the area of interest. The principles of falaj performance and construction are basically common to all such structures though they may differ in detail. The falaj provides an almost horizontal tunnel that taps ground water and leads it to a surface outlet where it can be used without having to resort to pumps or other mechanical lifting devices.

The distribution of known falages in use is shown in Fig. 8.2. However, there are many falages that have been abandoned, some in sufficiently recent times for traces of distributary channels and garden boundary walls to be observed along with the remnants of date palms that were once cultivated with the water. These include F. Murreqibai, F. Idhn, F. Mulayhah, F. Khudayra, as well as F's Zakha, Thanabi and ash Shaykh near the present F. al Mu'alla, and are indicated in Fig. 8.2.

To function properly, all parts of a falaj system (Fig.8.3) must be in a good state of repair. This includes (1) the mother well or wells that initially collect the water, (2) the very shallow but uniform grade of the tunnel floor that controls the flow of water from the collection point sometimes in the manner of a subsurface drain, (3) sealed vertical access shafts to the tunnel, formerly used for spoil removal and ventilation, and finally (4) the unhindered egress of water from the mouth of the tunnel. If any of these parts is damaged or not subject to regular maintenance, then the effect will be to restrict the yield from the falaj, leading to a progressive deterioration and final abandonment of the source. This rather than declining water levels is considered to be the reason for the fact that in the area of study there are more abandoned falages than working falages. The latter are tabulated below with some indications of the recorded range of their discharges. It is interesting to note that the largest range in discharge occurs in the falages in the 'mountain' unit whereas those located on the 'gravel plains' appear to have a more

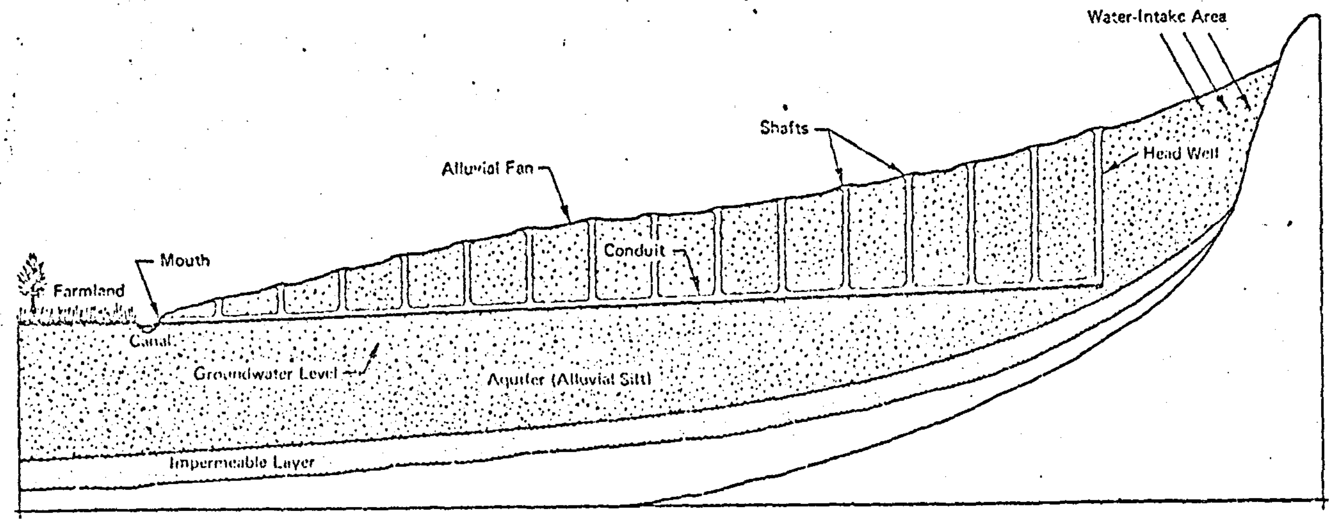


FIGURE 8.3 Exploiting the gradient of the natural terrain, qanat system is a series of wells dug into an underground water supply and connected by underground channels that convey water by gravity to the ground surface at lower levels. (Based on a diagram in *Scientific American*, Wulff, 1968. See Selected Readings.)

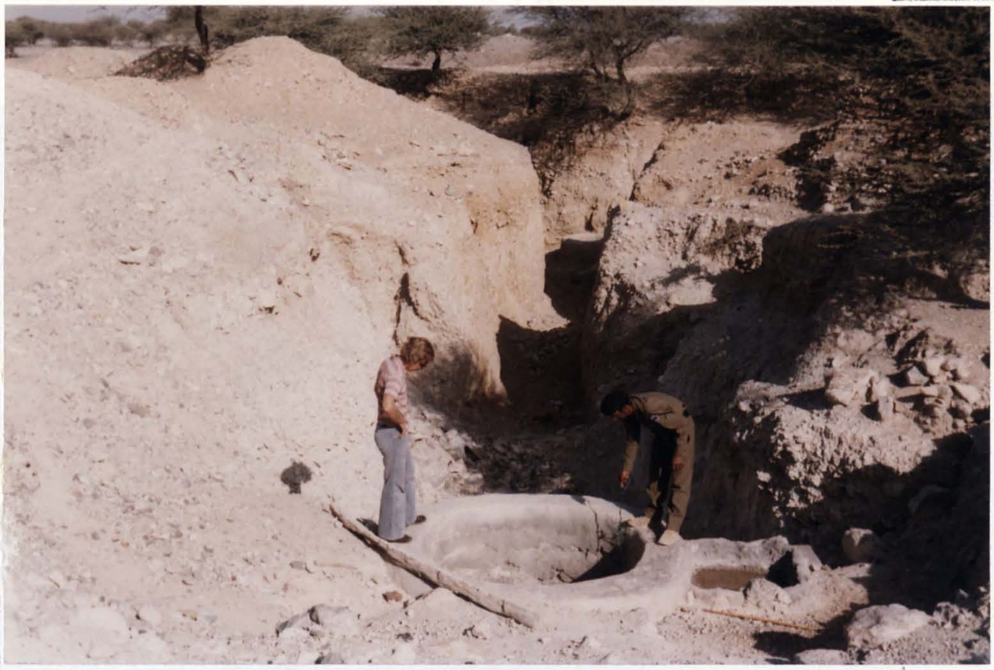


Photo 8.5: Source well in limestone pediment leading to Falaj in middle distance.

Photo 8.6: Source well in limestone overlain by reddish gravel deposits.

Photo. 8.7: Excavated channel leading ground water from limestone into falaj.

Photo. 8.8: Excavated channel tapping ground water in alluvial material.

Falaj	Maximum discharge (l/sec)	Minimum discharge (l/sec)	Seasonal ratio
Siji	283·2	24·1	11·8
Dhaid	22·7	15·6	1·5
al Mu'alla	12·5	9·1	1·4
Usayli (Khatt)	6·5	3·7	1·8
Manama	5·1	1·7	3·0

limited range. Two of the falaj systems are worth mentioning in more detail because they have been the subject of recent work.

In an attempt to increase the yield of the Khatt South 'spring', excavations have been undertaken recently in a manner consistent with falaj construction. The pool to the east of the road (see Fig.8.1) is fed from a channel which leads eastwards via a tunnel and shaft system with circular stone and cement-rimmed access shafts at 30 - 50 ft intervals. The tunnel and shafts become deeper as the falaj continues into sloping ground for up to 1 km and terminates (or originates so far as the water is concerned) in two 'mother' or source wells (Photographs 8.5 and 8.6). There is wholesale shift of strike lines which must be attributed to faulting in the limestone formation at this locality and the water is tapped from well-bedded and steeply-dipping limestones at the edge of the mountain ridge and led into the falaj system (Photographs 8.7 and 8.8).

In 1975, Hunting Technical Services Ltd., in association with Sir Alexander Gibb and Partners, undertook and reported on a feasibility study of the Falaj Dhaid in the south gravel plain area near the town of the same name. The plan, longitudinal- and cross-sections of the tunnel of the falaj are incorporated in Fig. 8.4, where it may be seen to have a Y-shaped form with subsidiary tunnels and an overall length exceeding 4 km. In part the falaj underlies the seasonal Wadi Dhaid from which some occasional

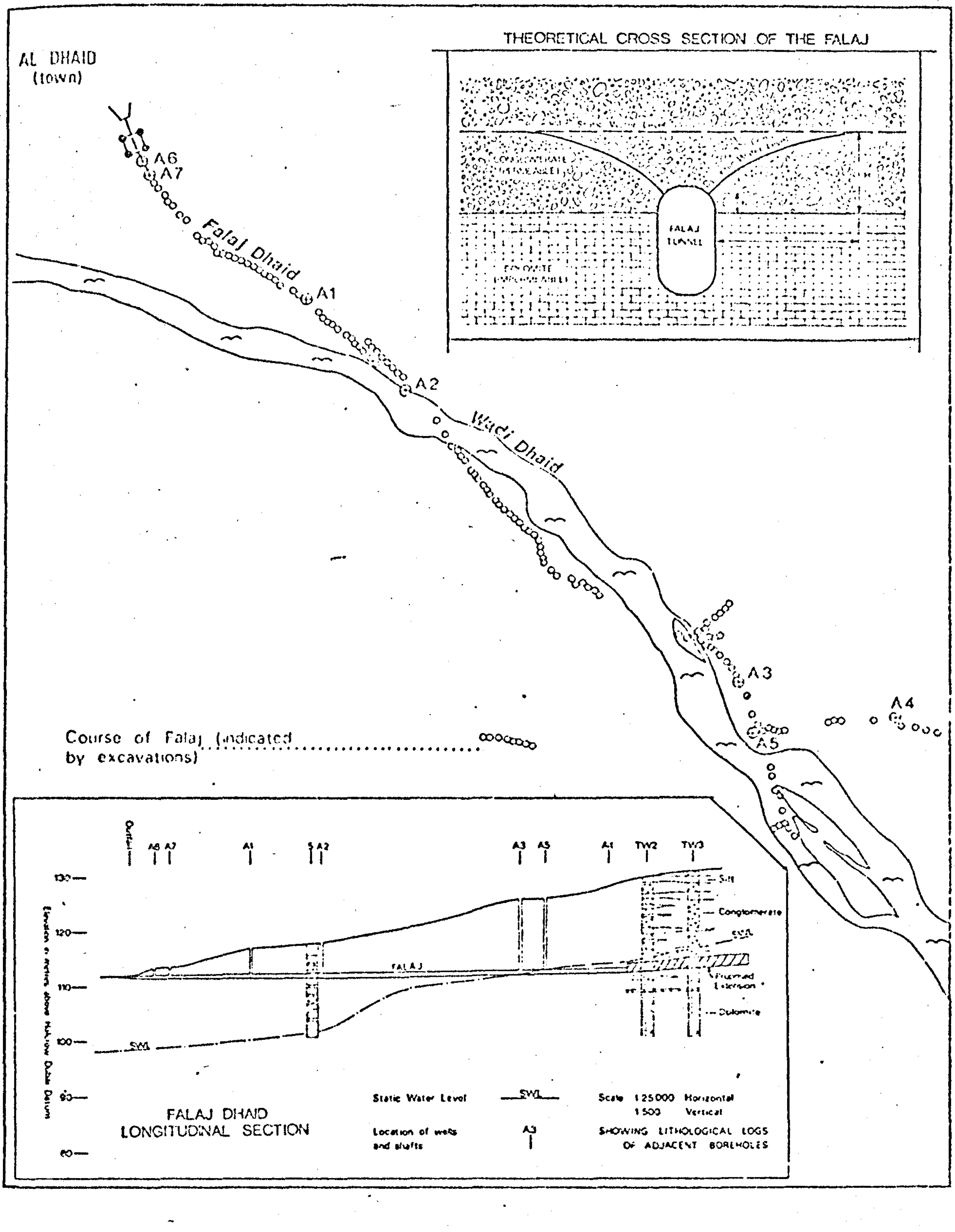


Fig. 8.4 Details of Falaj Dhaid

minor replenishment may be derived, though the report identified the cemented conglomerate as the major contributor with most of the water derived from the piedmont fans at the foot of the mountain. A radio-active tracer study undertaken by Harwell on behalf of Hunting Technical Services with Bromine 82 provided accurate information on flows in different parts of the falaj system. Thus a maximum flow of 24 l/sec occurred in the upper two kilometres of the falaj with a reduction by seepage losses of some 20 percent to 19·6 l/sec taking place by the time the mouth is reached.

Various recommendations were made for increasing the perennial yield of the falaj, the most important of which was the headward extension of the northern feeder branch for a further 1000 metres. Expected difficulties in obtaining skilled labour and the prolonged nature of the project led to the proposal to use modern tunneling methods at a cost which was only 14 percent more than traditional methods. Apart from silt removal and minor lining repairs, no extensions have yet (1978) been undertaken, and it seems unlikely that they ever will.

8.4 WELLS

Shallow hand-dug wells (tawis) have long been a traditional source of ground-water in the UAE as in most parts of the world and have certain advantages where the water table is at no great depth below the ground surface. They were relatively inexpensive and easy to construct and maintain by unskilled labour, and importantly provided both storage and source. So long as the water requirements were for domestic or stock watering purposes, sufficient supplies could be withdrawn by hand with the aid of pulley blocks (Photograph 8.9) or even the occasional 'shaduf'. However, as ground water came to be recognised as the primary source for garden purposes so the reliance on humans or animals for motive power imposed a constraint on the quantities that could practicably be extracted from

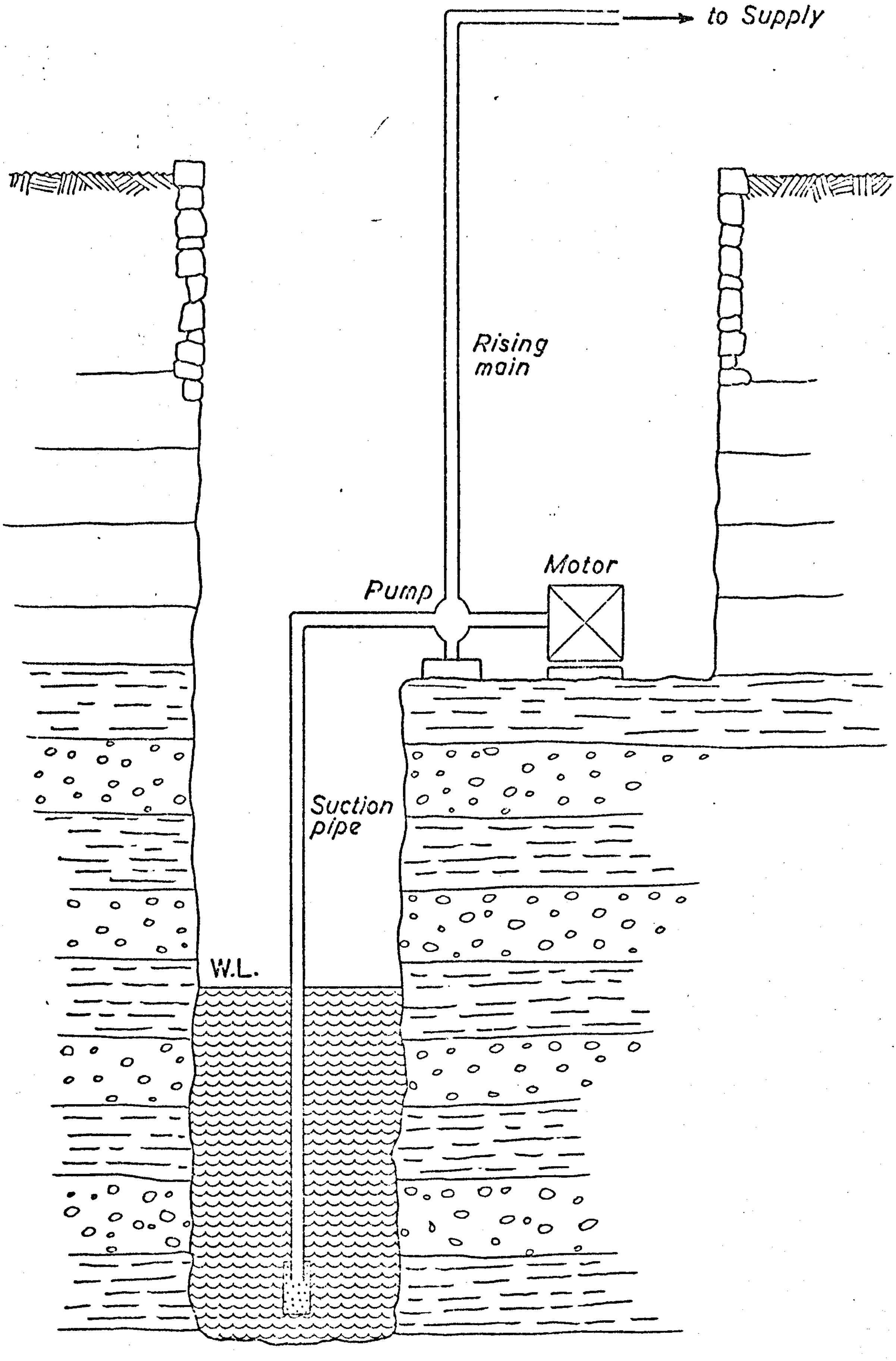


Fig. 8.5 Sketch of hand-dug well system.

Photo. 8.9: Shallow hand-dug well with pulley for manual raising of water.

Photo. 8.10: Belt driven turbine pump mounted over borehole.

shafts or hand-dug wells. The introduction of diesel-driven centrifugal or suction pumps solved the problem of raising the water in sufficient quantity for irrigation purposes but frequently required deepening of the wells to sustain such yields. Moreover, because of the limitations of suction lift it was frequently necessary to install the pump and motor inside the shaft within reach of the water surface as illustrated in Fig. 8.5. A more recent modification of this arrangement has been the introduction of the turbine pump which allows the pump and motor to be installed more conveniently at the top of the shaft.

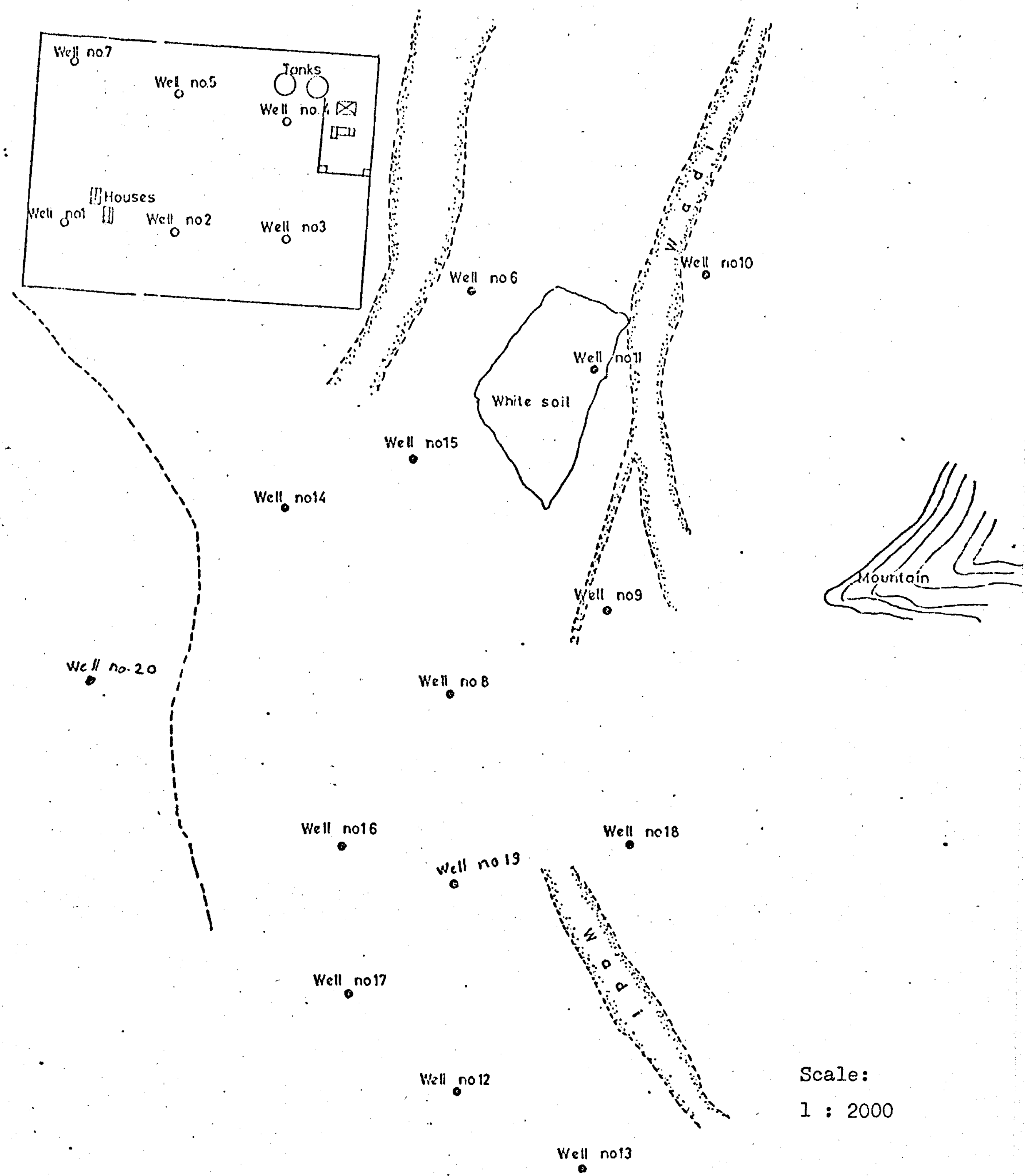
Where the water table occurs at depths that may be unsafe or inconvenient for hand digging then drilled wells (boreholes) are the obvious alternative. The slower method of construction is percussion drilling while the faster rotary method is the preferred method of the better drilling companies. Smaller farmers may prefer the percussion drilled holes which in the southern part of the study area are lacking in wall support other than a length of concrete pipe at the top of the well. A multi-stage turbine pump with canvas belt drive powered by a diesel engine is frequently used for motive power (Photograph 8.10). Elsewhere, rotary drilling with mud instead of water ensures faster penetration and better completion which, given the ever-increasing demand for drilled water wells in the UAE, allows competitive pricing that works out cheaper than percussion drilling. For domestic and industrial boreholes, rotary drilling is now the rule (Photographs 8.11 and 8.12) and is becoming commonplace for irrigation purposes.

Where larger centres of population impose high demands on water for domestic and general purposes, the individual drilled well supply is far too small and the result has been an expansion in the development of well-fields. The following tabulation summarises the situation in the study area:

Photo. 8.11: Rotary drilling on alluvial fan near Shamal.

Photo. 8.12: Rotary drilling in wadi gravels near Burairat.

BURAIRAT WATER WELL FIELD



Scale:
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Photo. 8.13: Part of Burairat wellfield.

Photo. 8.14: Extension of Sayh el Fahlayn wellfield.

Town	Wellfield
Ras al Khaimah	Burairat
Umm al Qaiwain	T. Zarka
Ajman	T. Rashid
Sharjah	T. Bida'at

Each of these comprises many wells spaced relative to one another at distances that inevitably produce interference effects of varying degree. An example of this is the Burairat wellfield referred to in previous sections and illustrated in Fig. 8.6. Nevertheless, the rapid growth in demand means that wellfield construction will have to continue until alternative supplies are provided (Photos. 8.13 and 8.14).

8.5 GROUND WATER COSTS

The cost of water for general domestic and irrigation use in the northern United Arab Emirates varies due to the following factors:

Total depth of the wells;
quality and quantity of the water;
type of formation penetrated;
method of drilling and developing;
type of engine, pump and capacity;
amount of pipe work and fittings;
storage tank reservoirs;
labour cost;
depth of irrigation and water use;
seasonal variations.

Total depth of the wells: It will be obvious that differences in water depths will affect the cost of drilling. For example, in Wadi Bih six kilometres away from Burairat towards the mountain range, drilling reached depths of 380 feet with the water table at 250 feet b.s., whilst in Burairat (the end of Wadi Bih) the drilling reached a depth of 280 feet with a water table depth of 180 feet. A further example is in the Shamal area not far from the shoreline, where the total depths of some wells are less than 100 feet with a water table depth of only a few feet below land surface.

Quality and quantity of the water: Although the quality and quantity of ground water differs throughout the UAE due to different hydrochemical conditions, the uses of water remain much the same, i.e. rural water, domestic water, irrigation, industrial, etc. The quantity of water produced also depends on may factors and as it changes from area to area it can affect the water cost.

Type of formation penetrated: This affects costs since it affects the discharge required, need for casing and screens, type of casing and screens, rate of penetration in drilling, as well as water quality.

Method of drilling and developing will affect the cost of water in the area due to the fact that percussion drilling is less cheap than rotary drilling techniques.

Type of engine, pump and capacity depends on the quality and quantity of the water, depth of the water table, fuel or electrical power consumed and the source of the power supply.

Amount of pipe work and fittings and their costs will differ due to the distance of transporting the water through pipes including the pro rata increase in fittings and will therefore affect the cost of both capital expenditure and maintenance.

Storage tank reservoirs differ in cost due to capacity, elevation and type. The type generally used in the northern part of the UAE are storage reservoir tanks made from pressed steel plates, elevated 20 to 70 feet above the area to be supplied.

Labour costs will differ from place to place in the northern part of the UAE due to local accommodation facilities.

Depth of irrigation and water use changes from area to area and affects the general costs of irrigation.

Seasonal variations will modify the general consumption of water as it increases in summer time, along with an increase in the evaporation rate so that the cost of water increases, especially for irrigation purposes.

Taking the previously mentioned factors into consideration, the Burairat area in Ras Al Khaimah has been selected to illustrate the calculation of the costs of water in the northern part of the UAE, since it represents many similar major ground water sources in the area and can therefore be used as a general guide. The water well field in Burairat is currently used for general supply purposes though plans are being made to use part of the water resources for irrigation.

The volume of water used per day is estimated at two million gallons, assuming that eight wells are working twenty to twentyfour hours per day with each well discharging approximately 250,000 g/day. The total volume of water used per annum is estimated to be 730 million gallons.

The total depth of the wells ranges from 250 to 280 feet with basic characteristics itemised as follows:

Well discharge:	10,000 to 12,000 g/hr
Casing and screens:	10 inch I.D. PVC type
Pumps:	6 Nos. wells - Grundfos 30 HP Electric Motor
	2 Nos. wells - Grundfos Diesel Turbine with Blackstone Engine 30 HP

For estimation of costs of drilling, one can assume a maximum depth of 280 feet by 14¾ inch diameter at 140 dirhams (Dhms) per foot so that

$$280 \times 140 = \text{Dhms } 39{,}200$$

Cost of casing and screens: 280 x Dhms 390 per foot + Dhms 109,200

Cost of pumping test: approximately Dhms 20,000 wells of Dhms 1,347,200.

Engine and Pump: Dhms 30,000 (assuming an engine cost of Dhms 17,000 and a pump cost of Dhms 13,000).

The expected pump and engine depreciation over 3 years is of the order of Dhms 10,000 per year.

The diesel (Gas/Oil) consumption is 0·2kg/HP and with the 30 HP pumps used, the consumption will be:-

$$30\text{HP} \times \frac{0{\cdot}2\text{kg/hr}}{\text{HP}} = 6\text{kg/hr which is}$$

equivalent to approx. 6·67 litres of gas/oil per hour.

In the Northern Emirates the cost of gas/oil is Dhms 2.45 per gallon and that of motor oil Dhms 20.00 per gallon, with the cost of electricity being Fils 25 per kw/hr (100 fils = 1 dirham). For a discharge of 50 m^3/hr with a head of around 50 metresas at Burairat, the required electric power is 10 kw/hr for the pump with an estimated generator efficiency of 0·5 to 0·6. With the pump working for 20 hours per day at a cost of 250 Fils for 10 kw/hr, the total expenditure would be 20 x 250 = 5,000 Fils or Dhms 50 per day. Electric motors are the most efficient source of power for pumping, though diesel engines or motor generators are frequently used as standby power for plants using electricity as their main source. For the consumption of fuel gas oil with the same pump in Burairat, the calculation is as follows:-

> Consumption is 6·67 litres gas oil per hr, so that in a 20 hour day, 133·4 litres or 29·25 gallons would be used. It follows that the cost per day is 29·25 x 2.45, which is Dhms 71.66. If one estimates the cost of lubricants and consumption of oil to be 20 percent of the fuel cost, they would amount to 71.66 X 0·2 = Dhms 14.33.
> Total cost of fuel and lubricant per day = 14.33 + 71.66 = Dhms 85.99 per day.
> Cost of fuel and lubricant per annum if year considered 365 days = 365 x 85.99 = Dhms 31,386.
> Cost of electricity consumption per year if year considered 365 days = 50 x 365 = Dhms 18,250

For eight wells - consumption of fuel and lubricant per annum = 31,386 x 8 = Dhms 251,090
For eight wells - consumption of electricity per annum = 18,250 x 8 = Dhms 146,000

The cost of generator for electric power should also be taken into consideration, and if 10 kw/hr used, the generator capacity is:-

$$\frac{kw}{0\cdot5} = \frac{10}{0\cdot5} = 20 \text{ KVA/hour}$$

the generator set of 20 KVA per hour = Dhms 30,000

Depreciation of generator sets and pumps will be 3 years and the well depreciation is estimated to be 10 years.

To summarise the cost of water extraction:-

	for single well (Dhms)	for eight wells (Dhms)
Cost of well	168,400.00	1,347,200.00
Cost of engine and pump	30,000.00	240,000.00
	198,400.00	1,587,200.00

The annual cost of wells if depreciation is over 10 years

$$= \frac{1,347,200.00}{10} = \text{Dhms } 134,720$$

while the annual cost of engine and pump with depreciation over 3 years

$$= \frac{240,000.00}{3} = \text{Dhms } 80,000$$

Direct costs

Electricity cost for 6 wells per annum in Burairat is 18,250 x 6 = Dhms 109,500;

fuel cost for the remaining 2 wells per annum in Burairat is 31,386 x 2 = Dhms 62,772;

total cost of electric power plus fuel per annum is Dhms 173,272;

cost of fuel and electric power for one year plus generator set with depreciation of Dhms 10,000 per annum is Dhms 183,272;

The considered minimum number of labourers required is 4 with a salary of

Dhms 1,500.00 per month, i.e. Dhms 18,000.00 per annum, giving total labour cost per annum of Dhms 72,000. For general maintenance it is estimated that one should spend one dirham for every 50,000 gallons of water pumped. On this basis the annual cost of maintencance would be

$$\frac{730,000,000.00}{50,000} = \text{Dhms } 14,600$$

The total costs per annum for water extraction is tabulated as follows:

	Dhms
Annual cost of wells per annum	134,720
Annual cost of engine and pump per annum	80,000
Total cost of electricity, fuel, generator per annum	183,272
Labour costs per annum	72,000
Maintencance cost per annum	14,600
Total costs	484,592

from which the cost per gallon of water extracted can be calculated to be

$$\frac{730,000,000}{484,592} = \text{Dhms } 0{\cdot}001$$

After the water is extracted, the uses to which the water is put depend on many factors.

In the FAO report (1973) on agricultural development in the UAE, prepared by the FAO technical advisory commission, an attempt was made to obtain data to calculate the cost of ground water used for irrigation in the UAE. The example that was used for study was a farm near Dhaid.

The farm had a 200 ft deep borehole which was uncased, and with a static water level at 16 ft below surface, was fitted with a vertical turbine pump with 26 HP Blackstone diesel engine. The borehole discharge was some 120 m^3/hour and it was fed into a storage tank having a capacity of 70^3m . With the pump working 200 days per annum and about 11 hours per day, the total abstraction was 264,000 m^3 per annum spread over 6 hectares growing fruit and vegetables.

Capital costs:

200 ft borehole	$ 1250
engine	3250
pump	3000
fittings	500
storage tank	500
	$ 8500

Annual fixed costs:

Depreciation on borehole @ 7%, 25 yr life	$ 106
Depreciation on tank @ 7%, 20 yr life	47
Depreciation on pump @ 7%, 14 yr life	72
	$ 1250

Direct costs:

Fuel (5 gallons diesel per day)	$ 212
Lubrication (20 percent of fuel costs)	42
Maintenance and repair (10 ¢ per 1000 m)	26
Labour	62
	$ 342

With an area irrigated of 60,000 m^2, and the volume of water used being 264,000 m^3/ann, the cost per m^3 of irrigation water is 0·603 ¢ and the cost per hectare irrigated is $265. Equivalent costs would be 0·0027 cents per gallon and, since 100 ¢ = 400 Fils, 0·01 Fils per gallon or 1 Fils per 100 gallons.

The cost of water for domestic and general use is best illustrated by taking the example of Ras Al Khaimah town and the supply from the Burairat wellfield. Most of the water well fields need a distribution system, and the type of pipe mainly used is asbestos cement. The diameter range of this pipe in the UAE is 10 inch in Ras Al Khaimah up to 24 inch diameter in Dubai. The water wellfield is approximately 30 kilometres from the town, and this distance will be used in the following calculations.

The cost of asbestos cement pipes including the necessary joints is:-

250 mm (10 inch) diameter	per mtr.	Dhms 82.00
300 mm (12 inch) diameter	per mtr.	Dhms 112.00
400 mm (16 inch) diameter	per mtr.	Dhms 140.00

Installation charges are estimated to be 100 percent including cost of pipe, connections and labour. Tank reservoirs are also required and the type mainly used are pressed steel storage tanks with a net capacity of 112,912 Imperial gallons, i.e. 36' x 32' x 16' deep single compartment, constructed from standard plates 4' square x 6 mm. These tanks could cost with construction charges Dhms 400,000 to Dhms 500,000. For a similar tank with a net capacity of 226,704 Imperial gallons, i.e. 48' x 48' x 16' deep single compartment, the cost with construction charges would be Dhms 1,000,000. Therefore, taking the pipe line length as 30 kilometres and the diameter of the pipe as 300 mm plus a tank of 226,704 Imperial gallons volume, the cost would be calculated as follows:

Cost for 30 kilometres pipeline = 112 x 1,000 = Dhms 112,000 x 30 = 3,360,000

Cost for pipe installation and ditches (approximately 100 percent) would be Dhms 3,360,000 which, with the cost of a 226,704 Imperial gallon storage tank would give a total cost of Dhms 7,720,000. Considering this pipe line is transporting 2 million gallons of water daily (i.e. 730 million gallons per annum), the expected depreciation of the pipe line would be over 5 years including the water tank, cost of pipe line, fittings and water reservoir would be Dhms 1,544,000 per annum. It follows that the approximate cost of 100 gallons of water after extraction would be

$$\frac{1,544,000.00}{730,000,000} \times 100 = \text{Dhms } 0.21 = \text{Fils } 21.$$

With added distribution costs of 1 Fils per 100 gallons of water, the estimated total production costs are 22 Fils per 100 gallons, which comes close to the selling price of water in Ras Al Khaimah of 20 Fils per 100 gallons.

9. WATER RESOURCES

9.1 Assessment of Resources

9.2 Water Balance

9.3 Future Development

9. WATER RESOURCES

Taking the study area in total, there is in general the paucity of water that one expects of an arid region. Whether the paucity can be described as shortage depends on the current use to which the water is put and the pattern of use in the forseeable future.

9.1 ASSESSMENT OF RESOURCES

The combination of sparse rainfall and high evaporation together with the infrequency of flood spates is more important than the lack of suitable damsites in minimising any role that surface water can play in contributing to the water supply situation in the northern UAE. This means that ground water is the sole important natural resource of relatively fresh water in the study area.

Ground water resources may be considered as of two kinds, renewable and non-renewable. Renewable resources are those which constitute replenishment to the aquifer and can be regarded as the water in temporary storage above the minimum long-term water level. They are temporary in the sense that they will decline with recession of water levels via springs, seepages and sub-surface flow during the dry season regardless of any artificial abstraction. The non-renewable resource is permanent in the sense that it is related to long-term storage defined as the amount of space available in the aquifer below the minimum of water levels.

Permanent resources are commonly considered to be in a steady state or equilibrium condition, and are usually large in relation to the renewable or replenishment resources. Where sufficient information is available, the permanent resources can be quantified by multiplying the volume of the saturated part of the aquifer by the specific yield of the aquifer material. This is not the amount of water which a unit volume of the aquifer can hold but rather is the quantity which can be released by gravity drainage, and is therefore more a function of grain-size distribution rather than porosity. Although reliable information on aquifer thickness is lacking, by approximating some of the parameters it is possible to derive an estimate of the permanent resources for all the ground water units other than the Mountain unit as tabulated below:

Ground Water Unit	Approx. area (km^2)	Sat. thick (m)	Vol. of sat. strata ($m^3 \times 10^8$)	Average specific yield	Perm. Resource ($m^3 \times 10^6$)
Gravel Plain (N)	500	25	125	0·10	1250
Gravel Plain (S)	250	20	50	0·05	250
Dune Sands	500	30	150	0·10	1500
Total	1250	-	325	-	3000

Various assumptions have had to be made which in the future can be refined as more accurate data are gathered, so that the results at this stage should be regarded as no more than indications that are correct to the nearest order of magnitude. The resultant estimated permanent resources are calculated to be some 3000 million m^3, but this needs to be kept in perspective since it would economically and technically be impractical to abstract all the available resource.

Temporary resources: That any significant replenishment to the ground water aquifer can take place in an arid region has long been a matter of discussion. In temperate regions such as Britain, seasonal replenishment may be proved from the seasonal fluctuation of ground water levels. In the northern UAE, however, such proof is less easy to obtain. There is nowhere any routine monitoring of well levels so that information of ground water fluctuations is widely scattered, intermittent and of short duration. Bearing in mind the fact that the wells in which such water level measurements have been made are either pumping wells or wells affected by adjacent pumping, then one can appreciate the difficulties in measuring and interpreting the results.

For instance, a winter rise may be due as much to general recovery from summer pumping as to replenishment. Such evidence as is available is inconclusive in places such as Ras al Khaimah, Digdaga and Dhaid, with occasional short term rises as in parts of the Madam Plain. The presence of long term replenishment is suggested by the maintenance of the gradient of the regional water table, the pattern of salinity changes along the direction of flow, and distortions of the regional hydrochemical trends by localised additions of fresh water.

The potential sources of such replenishment are two-fold:-

1) direct infiltration from rainfall, and
2) infiltration of surface runoff where concentrated in wadi channels.

It has been claimed (Ward, 1951; Wayland, 1953) for arid regions that in the presence of a blanket of sand up to 5 m thickness, direct replenishment to an underlying water table is impossible due to the slow rates of infiltration and the effectiveness of subsequent evaporation to those depths. On the other hand, Schoeller (1945) suggested that for the eastern Sahara with an annual rainfall of some 50 mm, local replenishment to the aquifer was possible via infiltration through the dune sands, and confirmation for the same area was provided when Conrad and Fontes (1970) by a study of the oxygen-18 content demonstrated the presence of isotopically enriched waters indicative of recent replenishment.

A study of greater relevance was that in the Dhana sand dune area of Saudi Arabia by Dincer <u>et al</u> (1974). They reported that

"observations of temperature gradients, moisture content, size distribution of the sand, and tritium, deuterium and oxygen 18 content of the moisture in the sand dunes in a very arid region show that a significant portion of an annual rainfall infiltrates through the sand dunes and can be a source of major recharge to the aquifer covered by the sand dunes."

The time distribution of the rainfall is of primary importance with light showers encouraging high evaporation and heavy storms apparently inducing deeper infiltration with less loss to evaporation. It is presumed that the latter conditions have prevailed sufficiently to allow some 20 mm of infiltration (25 percent of mean rainfall of 80 mm) to take place into the Dhana sands. A further constraining factor was the size distribution of the grains forming the sand mass. It was suggested that although no infiltration can take place when the mean annual rainfall is less than 50 mm, at values greater than this limit, infiltration would occur in direct proportion to the grain size of the sand material.

Such work is highly relevant to the study area since physiographically, climatologically and geographically they have much in common. Glennie (1970) has provided size distribution data for UAE dune sands which have a mean grain size ranging from 0·15 to 0·25 mm and, incidentally, show an improvement in sorting in upward direction. An attempt has been made in Figure 9.1 to graphically depict some of the major constraints on infiltration in the context of available information. It may be seen that to have any opportunity for direct replenishment to an underlying water table in northern UAE it would be necessary for a mean annual rainfall in excess of 75 mm to fall with relatively high intensity. It may occasionally happen that the necessary favourable combination of factors is satisfied but the likely frequency of occurrence is such that this should be ignored as a major mechanism of replenishment to the aquifer in the northern UAE.

With high run-off factors prevailing in the mountain regions, a large proportion of the rainfall makes its way into the wadi systems with some of that contribution reaching the wadi mouths as flood spates and the remainder entering the wadi fill material to comprise sub-surface flow. All previous workers in this area are agreed that the predominant source of replenishment to the gravel/conglomerate aquifer is derived from run-off from the mountains in their hinterland. Values for this component of run-off range from 10 to 20 percent.

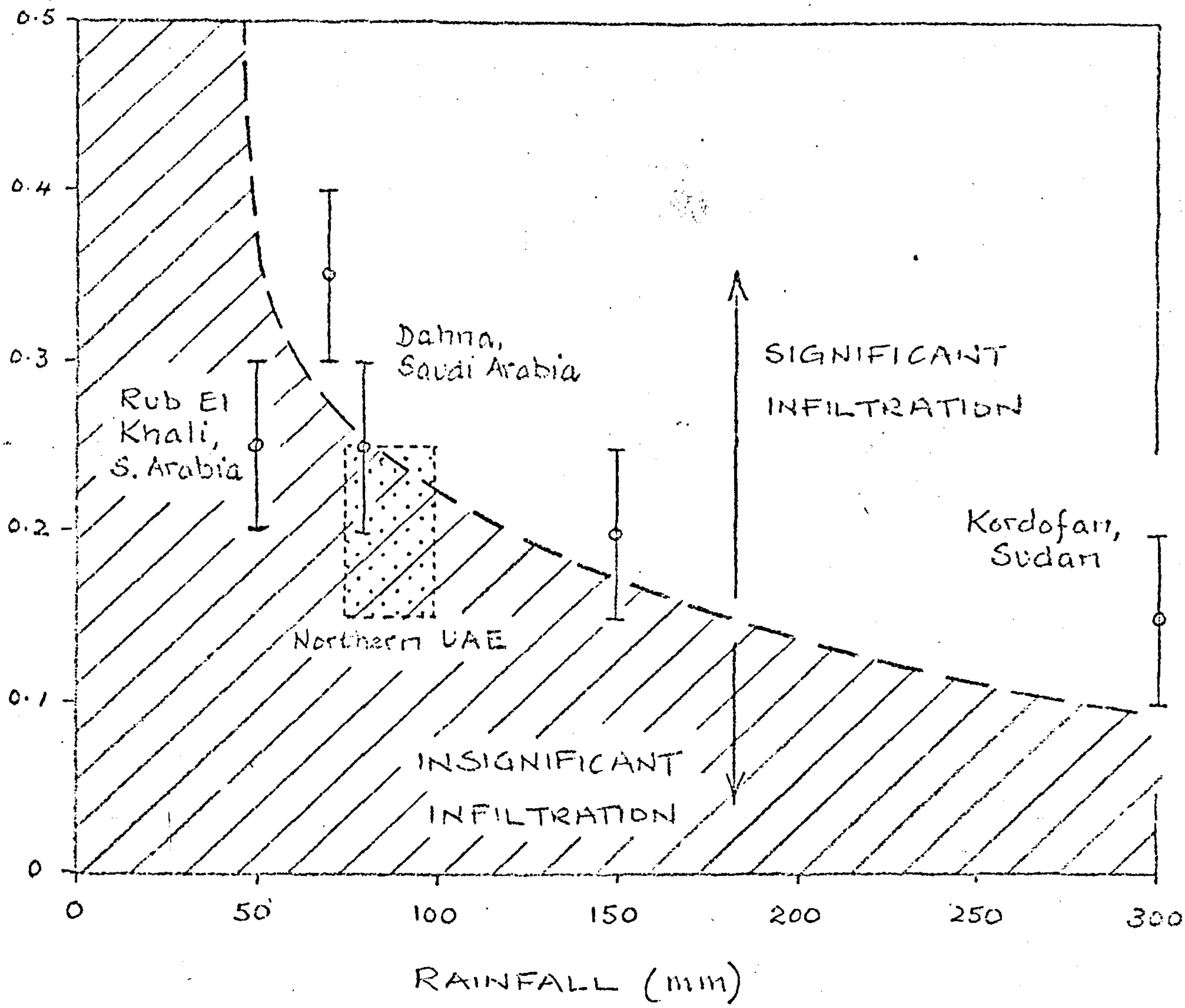

Fig. 9.1 Representation of major constraints on infiltration in arid regions

It should be emphasised that the rainfall and therefore the wadi spates are not regular annual occurrences. Indeed, it will be remembered that for the largest catchment, the Wadi Bih, there was no measurable surface flow at Burairat at any time from 1965 to 1967. Under such circumstances and with the absence of any rainfall station in the mountain region, even the estimation of the potential run-off contribution is fraught with difficulties. Be that as it may, the following tabulation is an attempt to obtain some idea of the quantity of potential replenishment:-

Unit	Area (km^2)	Rainfall (mm)	Volume ($m^3 \times 10^6$)	Run-off Factor ($m^3 \times 10^6$) 0·10	0·15	0·20
Gravel Plain (North)	1000	150	150	15	22·5	30
Gravel Plain (South)	250	150	37·5	3·75	5·6	7·5
Total	1250	-	187·5	18·75	28·1	37·5

An alternative method of calculating replenishment to the aquifer is to solve an equation derived from Darcy's Law and having the form

$$Q = T.i.w.$$

where T = transmissivity of the aquifer

i = hydraulic gradient

w = width of aquifer section across which flow is taking place

Transmissivities in the sectors of the aquifer have been assigned on the basis of values calculated in Chapter 6, to three sectors each of 25 km length that represents the length of the front across which ground water is deemed to be flowing. The resultant calculations are tabulated below:-

Sector	T (m^2/d)	i	W ($m \times 10^3$)	Q (m^3/day)	Q (m^3/ann.)
1	1500	0·001	25	37500	13·69M
2	1000	0·002	25	50000	18·25M
3	250	0·005	25	31250	11·41M
Total	-	-	-	-	43·35M

The two alternative estimates for renewable or replenishment resources give values of 37·5 and 43·35M m^3/annum and both are dependent on a number of arbitrary assumptions. A rounded off figure of 40 million m^3/annum may be regarded as having a correct order of magnitude which even if grossly inaccurate will remain exceedingly small in relation to the 3000 million m^3 of water held in storage.

9.2 WATER BALANCE

The water balance or hydrologic budget for an area or catchment aims at quantifying the different components of the hydrological cycle over some specified period of time. The budget theoretically should take into consideration all the water that enters, leaves or remains in storage in the area under study. The simplest equation of hydrologic equilibrium is:-

$$\text{INPUTS} = \text{OUTPUTS} \pm \Delta\text{STORAGE}$$

and when in a state of balance may be expressed (Jones, 1972) in the simple form:-

$$P = I + E + R$$

or in more detailed form:-

$$P = E_d + E_t + R_s + R_g \pm S_v \pm S_o \pm U$$

where:

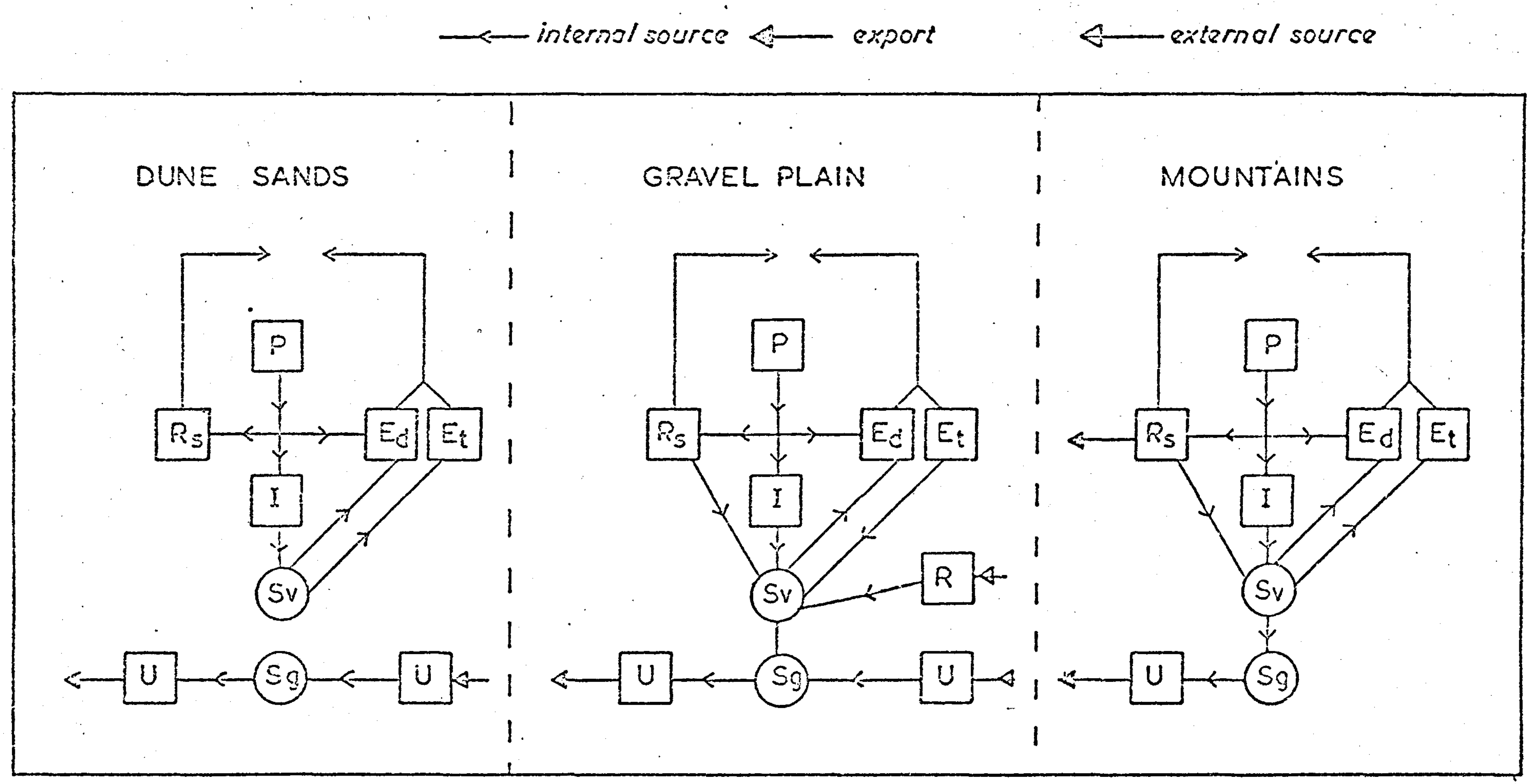

Fig. 9.2 Diagrammatic representation of components of the hydrological cycle in adjacent ground water units.

P	=	precipitation	E	=	evaporation = $E_d + E_t$
E_d	=	direct evaporation	E_t	=	transpiration
R	=	river discharge	= $R_s + R_g$		
R_s	=	surface runoff	R_g	=	ground water component
S_v	=	vadose water storage	S_g	=	ground water storage
U	=	underflow	I	=	infiltration

The conventional representation of these components refers to temperate humid conditions and needs considerable modification for the extreme nature of hydrologic conditions in the UAE. Furthermore, the hydrologic cycle applicable to the Mountain unit would be different from that in the gravel plains or the sand dunes units (see Fig.9.2). Given no significant change in climate, the natural state of the hydrological cycle would be one of equilibrium with short-term extremes balancing out over the long term. The need for a lengthy data base is to help determine what is normal and what is extreme.

Abstraction of water by man for any or all of the purposes of domestic, industrial and agricultural use will impose an additional 'output' on the system, and depending on the form of eventual disposal the water may be lost from the hydrologic cycle. In all three types of use there is some scope for a degree of recirculation or non-consumptive use, though it would probably be true to say that the water currently used is largely consumptive use and not available for conjunctive use.

It is extremely difficult to quantify the individual uses so that the overall abstraction must remain largely estimated. Domestic use will be greatest in the urban centres which are largely supplied with ground water from well-fields. The growth in population of such centres has been phenomenal as may be gauged from the tabulation below:-

Town	1968	1969	1970	1975
Ajman	4100	-	-	21600
Dubai	57400	63100	84100	206900
RAK	88700	9000	9800	57300
Sharjah	20600	-	30300	88200
UAQ	2900	3000	3300	16800

The growth rates have exceeded all forecasts and in the existing economic climate of the UAE further substantial increases must be anticipated. Quantification of the usage of water for urban purposes has been made by PCR (1973), UAE MAF (1975) and DAH (1976) and some data relevant to the study area are detailed below:-

	1969^t	1972^t	1975^s	1976^s
RAK	$0{\cdot}19Mm^3$	$0{\cdot}50Mm^3$	$3{\cdot}5Mm^3$	$3{\cdot}0Mm^3$
UAQ	0·05	0·17	1·7	(2)
Ajman	0·08	0·36	1.5	(2)

t = town s = state

The discrepancies in trend are due partly to the nature of the estimating procedure and partly to the fact that the small towns and villages were not included in the early data. This would be critical in Ras al Khaimah where in contrast to every other state in the UAE there is a larger population in the smaller towns than in Ras al Khaimah town itself. The figure of $7Mm^3$/ann is probably on the high side for current total urban abstraction in the study area.

The demand for water for agriculture is primarily directed towards the usage of water for irrigation purposes. Whilst the area of land under cultivation has not been surveyed on the ground, reference to aerial photographs by SWH (1969) and FAO (1972) produced estimates of 3527 and 3500 hectares respectively for the northern UAE, of which some 1800 hectares (Ha) were assigned to the study area. Making allowance for expansion since that time, one may expect an area in excess of 2000 Ha with future potential capable of increasing to about 3000 Ha.

Some figures for the quantities of water used for irrigation of different plants are given below:-

locality	plant	water used ($mm/m^3/ann$)
Digdaga	alfalfa	4661
Digdaga	winter vegetables	2250
Digdaga	cotton	2100
Dhaid	fruit and veg.	4400

and it is reasonable to assume an average value of 3·5 $m/m^2/ann$ as the current consumption. Even the average rate is excessive since the FAO report that only about 2 m/m^2 is needed for plant growth. However, given the high rates of evaporation it may well be that any water applied in excess of the plant requirements is to ensure the downward leaching of the salts which would otherwise accumulate in the soil and ultimately reduce crop yields. The average irrigation water depth of 3·5 m/m^3 multiplied by an assumed 2250 Ha of cultivated area gives a total extraction of some 79 Mm^3/ann. This total is appreciably smaller than the 131·6 Mm^3/ann reported by the MAF (1975) but compares favourably with the value of 87·5 Mm^3/ann calculated by SWH (1969).

The total quantity of water currently abstracted is considered to amount to 7 Mm^3/ann + 79 Mm^3/ann = 86 Mm^3/ann. Rearranging the water balance equation described at the beginning of this section one would obtain:-

$$\Delta S = 0 - I = 86 - 40 = 46 \ Mm^3/ann$$

The resultant change in storage has a negative value indicating the degree of overdevelopment, necessitating withdrawal from 'permanent storage'. Because of the nature of the estimates used, this imbalance is probably higher than the actual value which will need to be revised as more data become available. Figure 9.3 graphically indicates the situation with depletion of a finite volume of permanent storage with seasonal accretion. The curves for resources and consumption intersect after about 50 years at current rates of extraction but with increasing urban and agricultural demand the consumption curves will steepen and the exhaustion of the aquifer will occur up to 20 years earlier. So long as abstraction exceeds replenishment then depletion of the resource

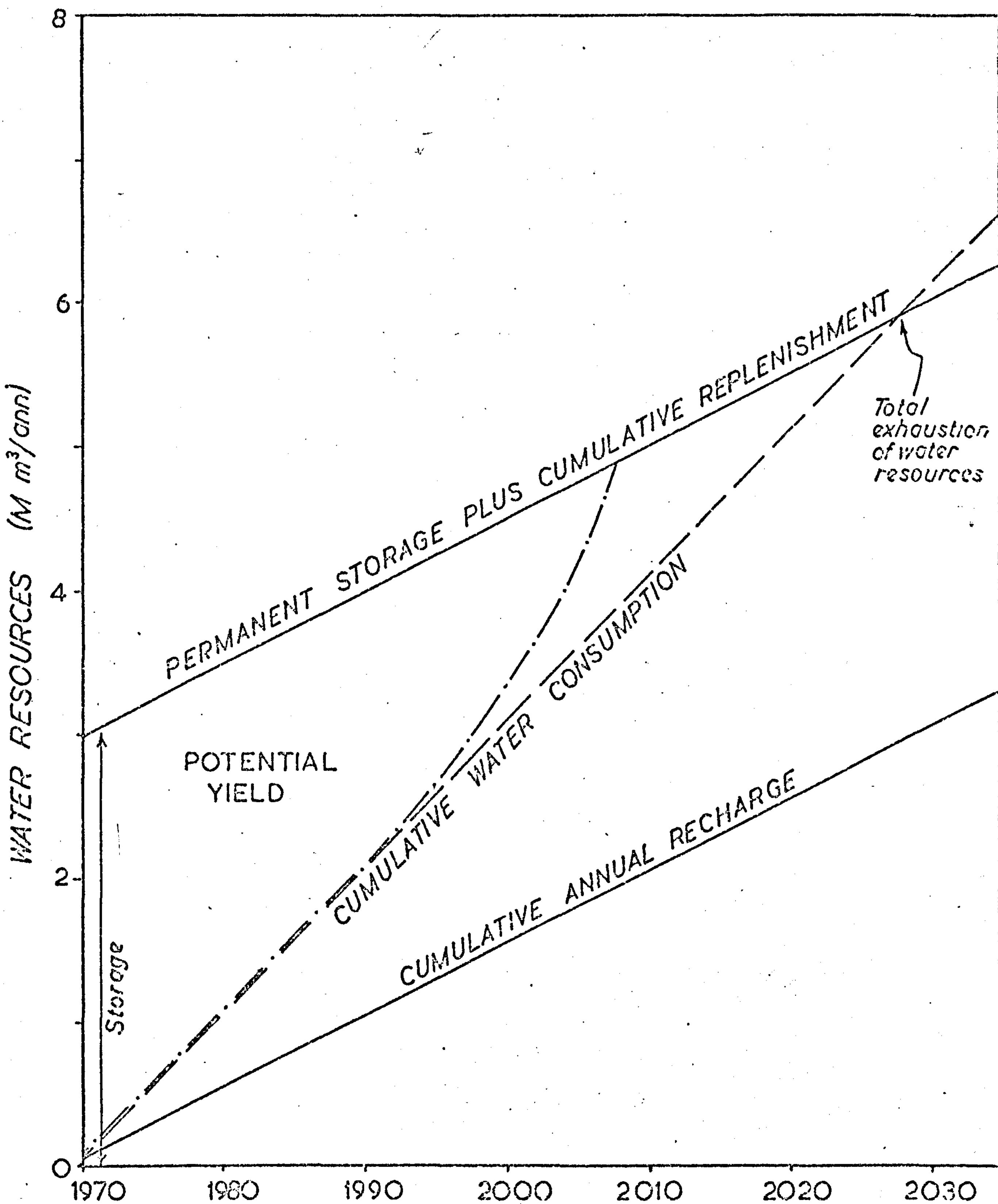

Fig. 9.3 Graphical representation of depletion of ground water resources.

is inevitable; errors in the estimates used for calculation purposes might change the time scale but not the eventual condition.

9.3 FUTURE DEVELOPMENT

Once the hydrological cycle has been modified by artificial abstraction it is necessary to resort to further modification to maintain equilibrium so that the standard balance equation would have the form $In + Ia = On + Oa + (\Delta S)$ where the subscripts 'n' and 'a' refer to natural and artificial respectively. There are only two ways in which the current situation might be improved; either the rate of extraction must be reduced or the rate of replenishment must be increased.

Reduction of demand requires primarily the elimination of waste or unnecessary use of water, and can be achieved by the following means:-

agricultural:
1) limitation of cultivated area
2) improved methods of water application
3) concentration on 'cash crops' to obtain greatest benefit from water used
4) introduction of licensing system with metered supplies

urban:
1) reduction of leakage from mains system
2) reduction of pressure in mains system
3) introduction of dual pipe system with two grades of water
4) introduction of block tariff system in combination with domestic metering

Various means are possible to increase the overall water resource available for use:-

1) recycling of treated sewage effluent for agricultural and garden uses;
2) modification of wadi-bed gravels so as to create storage reservoirs below ground level through the use of water tight membranes;
3) increase of ground water replenishment from flood spates through diversionary works aimed at impeding surface flow to enhance the opportunity for deep infiltration into the water table aquifer;

4) minimising of underflow to the sea through control of saline intrusion wedge by scavenger pumping or recharge of treated sewage effluent;

5) supplementation of supplies with desalinated sea water or brackish ground water.

Some combination of the previous alternative measures is already in use and emphasises the current desirability and the future inevitable need for unified management of the water resources regardless of use.

10. CONCLUSIONS AND RECOMMENDATIONS

10. CONCLUSIONS

One of the main objectives of this study was to emphasise that water resources are finite and given continuation of the prevailing conditions in the northern UAE, they will inevitably be affected for the worse both in quantity and quality.

The following are some of the conclusions drawn from the factual findings of the study regarding the main aims of the investigation as set out in section 1.6 of the introductory chapter.

(1) Study of the hydrogeological characteristics and properties of the major lithological units by reference to their occurrence, distribution, thickness, water-bearing and yielding capacities and their hydraulic inter-relationship.

The distinctive lithologies of the two major parts of the mountain zone that are separated by the 'Dibba Line' have directly and indirectly contributed towards the characteristics of the aquifer system that lies to the west between the mountain front and the coastline. The aquifer system has been interpreted as a layered aquifer sequence and in hydraulic continuity with a lower, lesss permeable unit. The northern part of the Gravel Plains has unconsolidated gravels of limestone and dolomite fragments underlain by limestones and marls, while in the southern part an indurated conglomeratic unit of igneous and metamorphic fragments overlies a dolomite and chert sequence. The total depth of the upper aquifer is unknown in the northern part as indeed is the detail of the assumed alternating layers and lenses of gravel, sand, silt and clay which tends to be masked by the method of drilling. Solution phenomena are well marked in the mountain exposures of the lower carbonate aquifer. There is, however, no information on their presence at depth and the hydraulic properties and yield potential of the carbonate aquifer are totally unknown though in the north their conditions are inferred to be unfavourable to water resources.

The major aquifer is the gravel/conglomerate and determination of hydraulic properties has been undertaken by conventional test pumping. It would appear as if some such values in the past have been over exaggerated by reliance upon inappropriate analytical methods. Re-analysis of the data indicates that the major aquifer is predominantly unconfined with storativity values of the order of 10^{-2} and transmissivities ranging from 250 to 2500 m^2/d in the gravels of the northern part but one order of magnitude less in the mudflow conglomerates of the southern part.

Variation in yields reflect differences in hydraulic conductivity, depth of saturated section and degree of development of the drilled hole. Well losses are consistently high at the prevailing pumping rates and it is concluded that this is due to insufficient development of the well after completion of drilling so as to ensure complete removal of mud and 'fines'.

(2) <u>Determination of the direction and quantity of ground water movement in order to determine replenishment zones</u>.

The water table stands at 200 m above msl along the mountain front in the south but only 5 m above msl in the north at Burairat. It declines in a general north-westerly direction towards the sabkha and tidal flats fringing the coast of the Arabian Gulf, with gradients being steeper in the south than in the west or north. The source of replenishment for the unconfined major aquifer is taken to be deep infiltration from occasional wadi flood spates and is restricted largely to those parts of the gravel plains adjacent to the mountain zone. Even so, there is no evidence of any 'build up' beneath the mouths of the major wadis. No replenishment from direct infiltration of the sparse rainfall is considered likely in the dune sands nor in those parts of the gravel plains away from the mountain front. The velocity of ground water flow is low and appears to range between 0·1 and 0·5 m/d, which tends to be confirmed by the pre-1954 tritium dating of the few samples that have been tested. It is unlikely that very much fresh water reaches the coastline due to the combination of excessive salinity, shallow depth and high evaporation within the tidal flats.

(3) Study of the chemical quality of the ground water and its suitability for domestic, industrial and agricultural purposes.

A wide scatter of sample localities shows a general correlation of increasing total dissolved solids (TDS) content with direction of flow, ranging from less than 1000 mg/l close to the mountain front in the south and rising to over 7000 mg/l and occasionally to as much as 10 000 mg/l. The tonguing of freshwater lobes in north-westerly direction probably reflects local replenishment from the more favoured wadis.

There are marked differences between the waters of the Gravel Plain (North) and Dune Sand units on the one hand and the Gravel Plain (South) and Mountain units on the other. The distinction extends to all elements and properties and is considered to be related partly to the lithological nature of the aquifer fragmental material but primarily to the incomplete flushing out of sea water associated with conditions prior to the relatively recent uplift of parts of the northern area. Considering the very high proportion of carbonate materials in the lithological sequences, it is notable that there are no waters of the expected calcium bicarbonate type.

In general, the ground water quality is poor with that in the Gravel Plain (North) and Dune Sand units being consistently worse than that from the other units. Many waters are worse than the WHO excessive limits for drinking water purposes and moreover have salinity and sodium values that require over-application of irrigation water for leaching purposes and need sandy soils with some restrictions on the type of crops.

(4) <u>Assessment of the ground water resources with reference to their present state and future development.</u>

Ground water is the sole natural resource of fresh water in the study area and also supplies a potentially important reservoir of brackish water. The permanent or non-renewable ground water resources are estimated to be about 3000 million m^3 with a long term average annual replenishment of some 40 million m^3. Abstraction to meet urban and agricultural demands is estimated to total over 80 million m^3/annum, more than double the mean replenishment, so that depletion of permanent storage is inescapable and eventual exhaustion inevitable if the present supply is not artificially supplemented.

The modifications that are likely to prove most successful are a limitation on the cultivated area with improved methods of irrigation water application; increasing of ground water replenishment through diversionary works; and the introduction of supplementary desalinated water.

The need for unified management of the water resource and its associated works is overwhelming against the background of conditions in the northern United Arab Emirates.

10.2 RECOMMENDATIONS

1. Confirm the nature of the aquifer system in northern UAE by a variety of means:-

   i) surface geophysics, resistivity methods have not been entirely satisfactory and it may be more successful to use seismic methods in combination with resistivity depth probing.

   ii) exploratory drilling; to provide geological information at strategic points by fully penetrating the upper layered aquifer to enter and prove the lithology and age of the underlying geology and confirm its potential as an aquifer.

   iii) geophysical borehole logging; to define aquifer characteristics by use of SP, Resistivity and Gamma Ray logs, with other logs such as flow velocity logs used as appropriate.

2. Survey and catalogue all existing wells (dug shafts and boreholes), collecting information on depth, diameter, use, lithology, static water level, pumping water level, yield etc., and ensure updating on an annual basis.

3. Test pumping of both upper and lower aquifers (where present) to determine aquifer properties and potential yields. Careful test pumping procedures after proper development of the drilled hole should include step-drawdown and constant rate tests, and allow for disposal of pumped water at distances sufficiently far to avoid recirculation in the prevailing water table conditions

4. Study the distribution of ground water quality paying particular attention to changes with time at selected sampling well sites and bearing in mind the constant danger of saline water intrusion.

5. Refine the estimated values for potential ground water reserves as more up-to-date information on replenishment, storage and abstraction becomes available.

6. Ensure that some system of unified management of water resources (including surface water, ground water and sewage water) is introduced as soon as possible, otherwise the storage reserves may be depleted beyond control.

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LIST OF APPENDICES

Borehole 4WR032

Location - Falaj al Mu'alla   Date of test 16 20.7.68

03839 E   28037 N   SWL below GL: 11.47 metres

t-min.after start of pumping	t_1-min.after stopping pump	log t/t_1	Drawdown metres	Remarks
0			0	Pump started
1			7.92	
1.5			9.14	
2			10.39	
2.5			11.68	
3			12.62	
4			13.16	
5			13.79	
6			15.29	
8			18.14	
10			19.02	
12			19.41	
14			19.68	
16			20.02	
18			20.07	
20			20.17	
25			20.22	
30			20.27	
35			20.32	
40			20.37	
50			20.40	
60			20.45	EC = 2650
70			20.50	
80			20.52	
100			20.57	
120			20.62	
140			20.68	Q = 7.6m^3/hr
160			20.75	
180			20.80	
210			20.85	
240			20.98	
300			21.08	
360			21.36	
420			21.54	
480			21.62	
540			21.72	
600			21.77	
660			21.84	
720			21.92	
1205			22.00	
1265			22.02	
1325			22.05	
1385			21.95	Q = 7.6m^3/hr
1445			22.00	
1505			22.02	EC = 2640

t-min.after start of pumping	t_1-min.after stopping pump	log t/t_1	Drawdown metres	Remarks
1565			22.05	
1625			22.07	
1685			22.05	
1745			22.10	
1805			22.07	
1865			22.02	
1925			22.05	
1985			22.07	
2045			22.10	
2105			22.12	
2645			21.89	
2705			21.84	
2765			21.82	
2825			21.77	$Q = 7.6 m^3/hr$
2885			21.74	
2945			21.69	
3005			21.67	
3065			21.59	EC = 2500
3125			21.56	
3185			21.54	
3245			21.54	
3305			21.56	
3365			21.54	
3425			21.51	
3485			21.54	
3545			21.54	
4085			21.29	
4145			21.23	
4205			21.15	
4265			21.08	$Q = 7.6 m^3/hr$
4325			21.06	
4385			21.03	EC = 2450
4445			20.98	
4505			20.93	
4565			20.90	
4625			20.88	
4685			20.90	
4745			20.83	
4805			20.85	
4865			20.88	
4925			20.83	
4985			20.80	
5525			20.65	EC = 2430
5585			20.57	
5645			20.62	$Q = 7.6 m^3/hr$
5705			20.62	
5765			20.68	EC = 2400
5825	0		20.62	Pump stopped
5826	1	5826 3.76536	18.52	
5826.5	1.5	3.58931	17.48	
5827	2	2914 3.46433	16.97	
5827.5	2.5	3.36755	16.41	

t-min.after start of pumping	t_1-min.after stopping pump		log t/t_1	Drawdown metres	Remarks
5828	3	1943	3.28840	15.29	
5829	4	1457	3.16350	14.71	
5830	5	1166	3.06668	13.77	
5831	6	972	2.98759	13.21	
5833	8	729	2.86280	12.52	
5835	10	584	2.76604	9.86	
5837	12	486	2.68700	7.37	
5839	14	417	2.62021	5.51	
5841	16	365	2.56236	3.86	
5843	18	325	2.51135	2.18	
5845	20	292	2.46574	1.30	
5850	25	234	2.36922	0.63	
5855	30	195	2.29039	0.48	
5860	35	167	2.22383	0.36	
5865	40	147	2.16619	0.30	
5875	50	118	2.07004	0.25	
5885	60	98	1.99159	0.20	
5895	70	84	1.92538	0.15	
5905	80	74	1.86813	0.13	
5925	100	59	1.77269	0.08	
5945	120		1.69496	0.03	
5965	140	43	1.62948	0.00	
5985	160		1.57294	- 0.01	
6005	180	33	1.52323	- 0.04	
6035	210	29	1.45846	- 0.09	
6065	240	25	1.40260	- 0.14	
6125	300	20	1.30998	- 0.19	
6185	360	17	1.23497	- 0.21	

Borehole 4WR033

Location - Falaj al Mu'alla Date of test 6 - 7.8.68

03838 E 28039 N SWL below GL: 11.08 metres

t-min.after start of pumping	t_1-min.after stopping pump	log t/t	Drawdown metres	Remarks
0			0	Pump started
1			3.25	
1.5			3.81	
2			4.93	
2.5			6.30	
3			6.55	
4			6.78	
5			7.03	
6			7.16	
8			7.21	
10			7.24	
12			7.29	
14			7.34	
16			7.39	
18			7.42	
20			7.44	
25			7.47	
30			7.49	
35			7.52	
40			7.54	
50			7.59	
60			7.64	
70			7.64	
80			7.69	
100			7.69	
120			7.70	$Q = 50.3 m^3/hr$
140			7.72	
160			7.75	
180			7.75	
210			7.77	
240			7.80	
300			7.82	
360			7.85	
420			7.87	
480			7.90	
540			7.95	
600			8.00	
660			8.00	
720			8.03	
780			8.03	
840			8.03	
1390			8.03	
1450			7.97	
1510			8.00	$Q = 50.3 m^3/hr$
1570			7.97	
1630			8.03	

t-min.after start of pumping	t_1-min.after stopping pump		log t/t	Drawdown metres	Remarks
1690				8.05	
1750				8.03	
1810				8.05	
1870				8.08	
1930				8.10	
1990				8.08	
2050				8.10	
2110				8.13	
2170				8.13	
2195	0			8.13	Pump stopped
2196	1	2196	3.34165	4.60	
2196.5	1.5	1464	3.16552	3.10	
2197	2	1099	3.04086	1.24	
2197.5	2.5	879	2.94399	0.66	
2198	3	733.3	2.86489	0.56	
2199	4	550	2.74017	0.41	
2200	5	440	2.64345	0.30	
2201	6	367	2.56447	0.25	
2203	8	275	2.43999	0.23	
2205	10	221	2.34339	0.21	
2207	12	184	2.26462	0.20	
2209	14	158	2.19806	0.20	
2211	16	138	2.14047	0.19	
2213	18	123	2.08970	0.18	
2215	20	111	2.04428	0.18	
2220	25	89	1.94841	0.18	
2225	30	74	1.87020	0.17	
2230	35	64	1.80424	0.17	
2235	40	56	1.74722	0.16	
2245	50	45	1.65225	0.16	
2255	60	38	1.57499	0.15	
2265	70	32	1.50996	0.15	
2275	80	28	1.45389	0.14	
2295	100	23	1.36081	0.13	
2315	120	19	1.28536	0.13	
2335	140	17	1.22215	0.12	
2355	160		1.16787	0.11	
2375	180	13	1.12036	0.10	
2405	210		1.05903	0.08	
2435	240	10	1.00626	0.08	
2495	300		0.91994	0.06	
2555	360	7	0.85109	0.05	
2615	420	6.23	0.79420	0.04	
2675	480	6	0.74609	0.04	

Borehole 6WR015

Location - Haremle

03843 E 28351 N

Date of test 7 - 19.6.68

SWL below GL: 18.31 metres

t-min.after start of pumping	t_1-min.after stopping pump	log t/t_1	Drawdown metres	Remarks
0			0	Pump started
1			2.21	
1.5			2.54	
2			2.69	
2.5			2.86	
3			2.98	
4			3.07	
5			3.12	
6			3.14	
8			3.21	
10			3.25	
12			3.29	
14			3.31	
16			3.34	
18			3.38	
20			3.42	
25			3.44	
30			3.47	
35			3.50	
40			3.56	
50			3.61	
60			3.68	
70			3.71	
80			3.71	
100			3.72	
120			3.72	EC = 3020
140			3.73	
160			3.73	
180			3.73	
210			3.75	
240			3.75	
300			3.76	
360			3.76	
420			3.77	
480			3.77	
540			3.77	Q = 38.0 m^3/hr
600			3.78	
660			3.78	
720			3.80	
1260			3.91	
1320			3.92	
1380			3.81	
1440			3.80	
1500			3.81	
1560			3.80	
1620			3.80	EC = 3040
1680			3.78	
1740			3.78	
1800			3.77	Q = 38.0 m^3/hr

t-min.after start of pumping	t_1-min.after stopping pump	log t/t_1	Drawdown metres	Remarks
1860			3.77	
1920			3.77	
1980			3.81	
2040			3.82	
2100			3.83	
2160			3.86	
2700			3.99	
2760			4.01	
2820			4.04	
2880			3.96	
2940			3.91	EC = 3070
3000			3.86	
3060			3.86	
3120			3.89	$Q = 38.0\ m^3/hr$
3180			3.89	
3240			3.91	
3300			3.94	
3360			3.92	
3420			3.91	
3480			3.90	
3540			3.94	
3600			3.95	
4140			4.04	
4200			4.04	
4260			3.99	
4320			3.96	
4380			3.94	
4440			3.89	
4500			3.86	EC = 3070
4560			3.83	
4620			3.86	$Q = 38\ m^3/hr$
4680			3.86	
4740			3.90	
4800			3.94	
4860			3.90	
4920			3.95	
4980			3.96	
5040			3.96	
5580			4.01	
5640			4.02	
5700			3.99	
5760			3.96	$Q = 38.0\ m^3/hr$
5820			3.91	
5880			3.94	
5940			3.89	
6000			3.94	
6060			3.95	
6120			3.96	
6180			3.94	
6240			3.99	
6300			4.00	
6360			4.01	
6420			4.06	
6480			4.04	
7020			4.11	
7080			4.11	
7140			4.06	

t-min. after start of pumping	t_1-min.after stopping pump		log t/t_1	Drawdown metres	Remarks
7200				4.11	
7260				4.16	
7320				4.09	EC = 3075
7380				4.14	
7440				4.11	Q = 38.0 m^3/hr
7500				4.16	
7560				4.22	
7620				4.27	
7680				4.29	
7740				4.32	
7800				4.32	
7840					Pump stopped
					Pump restarted after 2060 mins.
					TD of borehole = 32.9 m
0				0	
60				4.67	
120				4.72	
180				4.75	
240				4.57	
300				4.52	EC = 2950
360				4.50	Q = 30.4 m^3/hr
420				4.55	
480				4.55	
540				4.60	
600				4.66	
660				4.75	
720				4.83	
750	0				Pump stopped
751	1	751	2.87564	2.79	
751.5	1.5	501	2.69984	2.03	
752	2	376	2.57519	1.40	
752.5	2.5	301	2.47857	1.22	
753	3	251	2.39967	1.09	
754	4	189	2.27532	0.97	
755	5	151	2.17898	0.89	
756	6	126	2.10037	0.84	
758	8	95	1.97658	0.79	
760	10	76	1.88081	0.75	
762	12	64	1.80277	0.74	
764	14	55	1.73696	0.72	
766	16	48	1.68012	0.71	
768	18	43	1.63012	0.70	
770	20	39	1.58546	0.69	
775	25	31	1.49136	0.66	
780	30	26	1.41497	0.63	
785	35	22	1.35083	0.60	
790	40	20	1.29557	0.60	
800	50	16	1.20412	0.58	
810	60	14	1.13033	0.56	
820	70	12	1.06856	0.54	
830	80	10	1.01581	0.52	
850	100	8.5	0.92942	0.50	
870	120	7.3	0.86034	0.47	

t-min.after start of pumping	t_1-min.after stopping pump		log t/t_1	Drawdown metres	Remarks
890	140	6.4	0.80325	0.46	
910	160	5.7	0.75489	0.44	
930	180	5.2	0.71315	0.42	
960	210	4.6	0.66002	0.41	
990	240	4.1	0.61543	0.36	
1050	300	3.5	0.54407	0.32	
1110	360	3.1	0.48898	0.29	
1170	420	2.8	0.44483	0.27	
1230	480	2.6	0.40858	0.25	
1290	540	2.4	0.37825	0.22	
1350	600	2.3	0.35218	0.20	
1410	660	2.1	0.32959	0.18	
1470	720	2.0	0.31006	0.18	
0				0	Pump restarted 780 min after stopping
60				4.42	TD = 28.04 m
120				4.32	
180				4.34	
240				4.34	
300				4.34	
360				4.37	Q = 28.2 m^3/hr
420				4.42	
480				4.47	
540				4.52	
600				4.60	EC = 3000
660				4.65	
720				4.75	
780				4.78	
840				4.85	
1350				5.18	
1410				5.16	
1470				5.05	
1530				4.93	
1590				4.88	
1650				4.83	
1730				4.78	
1770				4.83	EC = 2925
1830				4.83	
1890				4.80	Q = 28.2 m^3/hr
1950				4.80	
2010				4.83	
2070				4.80	
2130				4.85	
2190				4.90	
2250				4.95	
2790				5.16	
2850				5.16	
2910				5.03	
2970				4.98	
3030				4.90	EC = 2900
3090				4.83	
3150				4.80	Q = 28.2 m^3/hr
3210				4.72	
3270				4.75	
3330				4.80	
3390				4.88	

Cable : "ZENDEBAD
Telephone : 27364

شركة تعلوير وحفر ابار المياه عبر ايران ـ فرع دبي

برقيا : زندباد
تلفون : ٢٧٣٦٤

SHERKAT ABYARI SARTASARI IRAN NAMAYANDEGI DUBAI

P. O. Box 4127 DUBAI (U.A.E.)

(Trans Iran Waterwell Drilling & Developing Co. Ltd.)

DUBAI BRANCH

Date May 18, 1975 التاريخ

Ref. Report 22 شماره

WELL NO 22(KHAT NO 1)

REPORT ON DEVELOPMENT OF WELLDRILLING & PUMP TESTING

1.	Owner of the well	:	Ministry of Electricity & Water, Dub
2.	Well site and No	:	Well No 22(Khat No 1) 300 ft from th previous well, towards main road
3.	Date of work commenced	:	1-5-75
4.	Date of work completed	:	12-5-75
5.	Total depth & dia of well	:	193' x 17½" bore hole
6.	Casing type and dia	:	12" I.D. Steel casing
7.	Length of casing installed	:	64'
8.	Screen type and dia	:	12" I.D. German bridge slotted bitumenized screens
9.	Length of screens installed	:	130'
10.	Duration of pumping test	:	72 hrs
11.	Type of pump installed	:	8 stage M23, worthington oil lubricated - 190' deep
12.	Mean discharge (per minute)	:	6000GPH
13.	Static water level	:	40'
14.	Maximum drawdown	:	112'
15.	Pumping commenced	:	14-5-75
16.	Pumping ceased	:	17-5-75
17.	Specific capacity of pump	:	450 GPM
18.	Surging, jetting & developing	:	24 hrs
19.	Soil formation in brief	:	Conglaraments changing from soft to hard with red sticky clay increasing and decreasing in clay continuously from 180' very hard conglaraments to 193'
20.	Water taste & condition	:	Sand free, normal drinking water
21.	Reccommendation	:	Fit for human consumption

For Sherkat Abyari Sartasari Iran

DL

Cable : "ZENDEBAD
Telephone : 27364

شركـة تطوير وحفر ابار المياه عبر ايران ـ فرع دبـي

برقيا : زندباد
تلفون : ٢٧٣٦٤

SHERKAT ABVARI SARTASARI IRAN NAMAYANDEGI DUBAI

P. O. Box 4127 DUBAI (U.A.E.)

(Trans Iran Waterwell Drilling & Developing Co. Ltd.)

DUBAI BRANCH

Date May 18,1975 التاريخ

Ref. Data 22 شماره

WELL NO 22(KHAT NO 1)

PUMPING TEST DATA AND MEASUREMENTS

Date	Time Started (min)	Depth to water (ft)	Drawdown (ft)	Pumping rate (GPH)
13-5-75	0	40.00	-	-
	1	45.42	5.42	6000
	2	57.38	17.38	"
	3	73.71	33.71	"
	4	81.69	41.69	"
	5	95.38	55.38	"
	6	102.51	62.51	"
	7	108.71	68.71	"
	8	117.05	77.05	"
	9	125.17	85.17	"
	10	131.63	91.63	"
	12	138.88	98.88	"
	14	146.61	106.61	"
	16	147.30	107.30	"
	18	147.80	107.81	"
	20	148.20	108.20	"
	25	148.70	108.75	"
	30	149.32	109.32	"
	35	149.78	109.78	"
	40	150.00	110.00	"
	45	150.31	110.31	"
	50	150.67	110.67	"
	55	150.89	110.89	"
	60	151.05	111.05	"
	70	151.27	111.27	"
	80	151.53	111.53	"

Cable : "ZENDEBAD
Telephone : 27364

برقيا : زنده‌باد
تلفون : ٢٧٣٦٤

شركة تطوير وحفر ابار المياه عبر ايران - فرع دبي

SHERKAT ABYARI SARTASARI IRAN NAMAYANDEGI DUBAI

P. O. Box 4127 DUBAI (U.A.E.)

(Trans Iran Waterwell Drilling & Developing Co. Ltd.)

DUBAI BRANCH

Date May 18, 1975 التاريخ

Ref. Data cont'd 2 شماره

Date	Time started (min)	Depth to Water (ft)	Drawdown (ft)	Pumping rate (GPM)
13-5-75	90	151.74	111.74 ✓	6000
	100	151.92	111.92 ✓	"
	110	152.00	112.00 ✓	"
	120	152.00	112.00 ✓	"
	150	152.00	112.00	"
	180	152.00	112.00	"
	360	152.00	112.00	"
	420	152.00	112.00	"
	480	152.00	112.00	"
	540	152.00	112.00	"

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

Site and Well No.	締 Burairat Well No. 3
Drilling Started Date	7.5.1976
Drilling Completion Date	10.5.1976
Total Depth	250 feet
Casing From	0 to 188 feet
Screens From	188 to 250 feet
Casing Diameter and Type	13 3/8 inch mild steel
Screen Diameter and Type	12 3/4 inch Johnson Stainles Steel
Duration of Pumping Test	48 hours
Pump Installed	8 inch Grundfos
Mean Discharge per hour (Q)	30.960 m^3/h
Static Water Level	50.72 metres
Maximum Drawdown	2.76 metres
Pumping Test Commenced	14.5.1976 4 p.m.
Pumping Test Completed	16.5.1976 4 p.m.

السشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

RAS AL KHAIMAH, WELL NO. 3 BURAIRAT

Depth in feet From	to		Lithological Description
0	40	Gravel:	Poorly sorted, fine to coarse, predominantly rounded and subrounded, light grey limestone, some light brown sandstone, some quartz Estimated meansize coarsiest fraction increases downward from about 10 mm to about 35 mm
40	60	Gravel:	Poorly sorted, fine to coarse, predominantly rounded, light grey limestone, some light brown sandstone, some quartz Estimated meansize coarsiest fraction about 20 -25 mm
60	100	Gravel:	Poorly sorted, fine to coarse, predominantly rounded and subrounded, light grey limestone, some sandstone, some quartz Estimated meansize coarsiest fraction about 15 - 20 mm Percentage of coarsiest fraction increases downward
100	140	Gravel:	Poorly sorted, fine to coarse, predominantly rounded and subrounded, light grey limestone, some light brown sandstone, some quartz Estimated meansize of coarsiest fraction increases downward from about 10 mm to about 25 mm
140	180	Gravel:	Poorly sorted, fine to coarse, predominantly rounded and subrounded , limestone, some sandstone, some quartz Estimated meansize coarsiest fraction 15 to 20 mm Slight increase of percentage coarsiest fraction downward

Cont.../

RAS AL KHAIMAH, WELL NO. 3 BURAIRAT Cont.

Depth in feet		Lithological Description
From	to	
180 -	240	Gravel: Poorly sorted, fine to coarse predominantly rounded and subrounded, light grey limestone, some sandstone, some quartz Estimated meansize coarsiest fraction 10 to 15 mm
240 -	250	Gravel: Poorly sorted, fine to coarse predominantly rounded and subrounded, light grey limestone, some sandstone, some quartz Estimated meansize coarsiest fraction about 10 mm

INTERNATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

SITE RAS AL KHAIMAH. WATER SUPPLY. BURAIRAT.

WELL No. 3

DATE STARTED 14.5.1976

DATE COMPLETED 16.5.1976

DURATION OF TEST 48 HOURS OUTPUT 30,960 m^3/h

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	50.72	210	53.35	1020	53.48
1	51.23	240	53.41	1050	53.48
2	51.31	270	53.45	1080	53.48
3	51.68	300	53.48	1110	53.48
4	51.94	330	53.51	1140	53.48
5	52.11	360	53.51	1170	53.48
6	52.17	390	53.49	1200	53.48
7	52.21	420	53.48	1230	53.48
8	52.24	450	53.48	1260	53.48
9	52.27	480	53.48	1290	53.48
10	52.29	510	Equilibrium Condition	1320	53.48
12	52.34	540	53.48	1350	53.48
14	52.38	570	53.48	1380	53.48
16	52.42	600	53.48	1410	53.48
18	52.47	630	53.48	1440	53.48
20	52.50	660	53.48		
25	52.57	690	53.48		
30	52.63	720	53.48		
35	52.67	750	53.48		
40	52.71	780	53.48		
45	52.75	810	53.48		
50	52.79	840	53.48		
55	52.83	870	53.48		
60	52.87	900	53.48		
70	52.94	930	53.48		
80	52.98	960	53.48		
90	53.02	990	53.48		
100	53.05				
110	53.07				
120	53.09				
150	53.18				

RECOVERY DATA

RECOVERY IN MINS

t' Mins.	Water Level in m.	t' Mins.	Water Level in m.	t' Mins.
0	53.47	360	51.32	720
30	53.46	390	51.25	750
60	53.46	420	51.21	780
90	53.40	450	51.17	810
120	53.32	480	51.07	
150	53.10	510	51.02	
180	52.46	540	50.95	
210	52.35	570	50.92	
240	52.21	600	50.90	
270	51.90	630	50.85	
300	51.56	660	50.83	

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. C 7563/ST/1

CONSTANT RATE PUMPING TEST

Site:	Sha'm
Well No.:	Piezometric P6
Date and Time Started:	21.5.1977 09.00 hours
Date and Time Completed:	22.5.1977 06.10 hours
Duration:	21 hours
Discharge:	104 m^3/hr.
Drawdown:	0.40 m
Static Water Level:	19.79 metres (ground level)
Amount of Casing above ground level:	1.00 metre

CONSTANT RATE - PUMP TEST

E	SHA'H	DISCHARGE	104 m^3/hr.
LL No.	PIEZOMETRIC P6		
TE STARTED	21.5.1977 09.00 HOURS	S.W.L.	19.79 metres (ground level)
TE COMPLETED	22.5.1977 06.10 HOURS		
RATION OF TEST	21 HOURS		

NS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
	20.79	210	21.10	1020	21.19
		240	21.11	1050	21.19
	21.030	270	21.12	1080	21.19
	21.040	300	21.13 =Pumping Strd. P2	1110	21.19
	21.040	330	21.14 & P3	1140	21.19
	21.040	360	21.15	1170	21.19
	21.040	390	21.16	1200	21.19
	21.045	420	21.16	1230	21.19
	21.050	450	21.16	1260	21.19
	21.050	480	21.17	1290	
	21.050	510	21.17	1320	
	21.055	540	21.18	1350	
	21.055	570	21.18	1380	
	21.055	600	21.18	1410	
	21.055	630	21.18	1440	
	21.050	660	21.19		
	21.050	690	21.19 P2 & P3 Stopped		
	21.055	720	21.19		
	21.055	750	21.19		
	21.055	780	21.19		
	21.055	810	21.19:		
	21.055	840	21.19		
	21.057	870	21.20		
	21.057	900	21.20		
	21.057	930	21.20		
	21.057	960	21.20		
	21.070	990	21.19		
	21.080				
	21.080				
	21.080				
	21.09				
	21.10				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7542/WE/1

RECOVERY TEST

Site:	Sha'm
Well No.:	Piezometric P6
Date and Time Started:	22.5.1977 06.10 hours
Date and Time Completed:	22.5.1977 11.10 hours
Duration:	5 hours
Discharge:	104 m^3/hr.
Original Water Level:	20.79 metres
Unrecovered Depletion:	0.10 metres
Amount of Casing above ground level:	1.00 metre

	SHA'H	DISCHARGE	104 m^3/hr.
No.	PIEZOMETRIC P6	ORIGINAL WATER LEVEL:	20.79 metres
STARTED	22.5.1977	06.10 HOURS	
COMPLETED	22.5.1977	11.10 HOURS	
TION OF TEST	5 HOURS		

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
21.21	210	20.89	1020	
20.96	240	20.89 P2 Started	1050	
20.96	270	20.89	1080	
20.95	300	20.89	1110	
20.95	330		1140	
20.95	360		1170	
20.95	390		1200	
20.95	420		1230	
20.95	450		1260	
20.95	480		1290	
20.94	510		1320	
20.94	540		1350	
20.94	570		1380	
20.94	600		1410	
20.94	630		1440	
20.94	660			
20.93	690			
20.93	720			
20.92	750			
20.92	780			
20.92	810			
20.92 P3 Started	840			
20.91	870			
20.91	900			
20.91	930			
20.91	960			
20.91	990			
20.91				
20.91				
20.91				
20.90				
20.90				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. C [illegible]

CONSTANT RATE PUMPING TEST

Site:	Sha'm
Well No.:	P5
Date and Time Started:	21.5.1977 09.00 hours
Date and Time Completed:	22.5.1977 06.10 hours
Duration:	21 hours
Discharge:	104 m^3/hr.
Drawdown:	0.12 m
Static Water Level:	21.57 metres (ground level)
Amount of Casing above ground level:	0.78 metres

CONSTANT RATE - PUMP TEST

...E	CHA'H		DISCHARGE 105 m³/hr.
...LL No.	P3		
...TE STARTED	21.5.1977	09.00 HOURS	S.W.L. 21.57 metres (Ground Level)
...TE COMPLETED	22.5.1977	06.10 HOURS	
...RATION OF TEST	21 HOURS		

...NS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
	22.35	210	22.41	1020	22.47
	22.35	240	22.41	1050	22.47
	22.34	270	22.41	1080	22.47
	22.34	300	22.41 Pumping Strd. P2	1110	22.47
	22.34	330	22.44 & P3	1140	22.47
	22.34	360	22.46	1170	22.47
	22.34	390	22.46	1200	22.47
	22.34	420	22.48	1230	22.47
	22.34	450	22.48	1260	22.47
	22.35	480	22.49	1290	
	22.36	510	22.50	1320	
	22.38	540	22.51	1350	
	22.38	570	22.51	1380	
	22.38	600	22.52	1410	
	22.38	630	22.52	1440	
	22.38	660	22.53		
	22.38	690	22.40 Stopped P1 & P3		
	22.38	720	22.48		
	22.38	750	22.48		
	22.38	780	22.48		
	22.38	810	22.48		
	22.38	840	22.48		
	22.38	870	22.48		
	22.38	900	22.48		
	22.38	930	22.48		
	22.38	960	22.47		
	22.38	990	22.47		
	22.40				
	22.40				
	22.40				
	22.40				
	22.40				

RECOVERY IN MINS

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G [illegible]/1

RECOVERY TEST

Site:	Sha'm
Well No.:	P5
Date and Time Started:	22.5.1977 06.10 hours
Date and Time Completed:	22.5.1977 11.10 hours
Duration:	5 hours
Discharge:	104 m^3/hr.
Original Water Level:	22.35 metres
Unrecovered Depletion:	0.12 metres
Amount of Casing above Ground level:	0.70 metres

NTERNATIONAL WATER WELL DRILLING CO. DUBAI

RECOVERY - PUMP TEST

E SHA'N

LL No. P5

TE STARTED 22.5.1977 06.10 HOURS

TE COMPLETED 22.5.1977 11.10 HOURS

RATION OF TEST 5 HOURS

DISCHARGE 105 m³/hr.

ORIGINAL WATER LEVEL: 22.35 metres

NS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	22.47	210	22.47	1020	
1	22.47	240	22.47 P2 Started	1050	
2	22.47	270	22.47	1080	
3	22.47	300	22.47	1110	
4	22.47	330		1140	
5	22.47	360		1170	
6	22.47	390		1200	
7	22.47	420		1230	
8	22.47	450		1260	
9	22.47	480		1290	
10	22.47	510		1320	
12	22.47	540		1350	
14	22.47	570		1380	
16	22.47	600		1410	
18	22.47	630		1440	
0	22.47	660			
5	22.47	690			
0	22.47	720			
5	22.47	750			
0	22.47	780			
5	22.47	810			
0	22.47 P3 Started	840			
5	22.47	870			
0	22.47	900			
0	22.47	930			
0	22.47	960			
0	22.47	990			
00	22.47				
10	22.47				
20	22.47				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. C 7543/WT/1

CONSTANT RATE PUMPING TEST

Site:	Sha'm
Well No.:	P1
Date and Time Started:	21.5.1977 09.00 hours
Date and Time Completed:	22.5.1977 06.10 hours
Duration:	21 hours
Discharge:	104 m^3/hr.
Drawdown:	0.15 m
Static Water Level:	19.43 metres
Amount of Casing above ground level:	0.22 metres

ERNATIONAL WATER WELL DRILLING CO. DUBAI

CONSTANT RATE - PUMP TEST 281

SHA'H

DISCHARGE 104 m^3/hr.

No. P1

S.W.L. 19.43 metres (ground level)

STARTED 21.5.1977 09.00 HOURS

COMPLETED 22.5.1977 06.10 HOURS

TION OF TEST 21 HOURS

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
19.65	210	19.74	1020	19.80
19.65	240	19.74	1050	19.80
19.66	270	19.75	1080	19.80
19.66	300	19.75 Pumping Strd. P2	1110	19.80
19.66	330	19.77 & P3	1140	19.80
19.67	360	19.79	1170	19.80
19.67	390	19.80	1200	19.80
19.67	420	19.81	1230	19.80
19.68	450	19.82	1260	19.80
19.68	480	19.83	1290	
19.68	510	19.84	1320	
19.68	540	19.85	1350	
19.68	570	19.85	1380	
19.68	600	19.86	1410	
19.68	630	19.86	1440	
19.69	660	19.87		
19.69	690	19.82		
19.69	720	19.82		
19.70	750	19.82		
19.70	780	19.82		
19.70	810	19.82		
19.70	840	19.82		
19.71	870	19.82		
19.71	900	19.82		
19.71	930	19.81		
19.71	960	19.80		
19.72	990	19.80		
19.72				
19.72				
19.72				
19.73				

RECOVERY IN MINS

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. C 7549/[illegible]/1

RECOVERY TEST

Site:	Sha'm
Well No.:	P1
Date and Time Started:	22.5.1977 06.10 hours
Date and Time Completed:	22.5.1977 11.10 hours
Duration:	5 hours
Discharge:	104 m^3/hr.
Original Water Level:	19.65 metres
Unrecovered Depletion:	0.12 metres
Amount of Casing above ground level:	0.22 metres

ERNATIONAL WATER WELL DRILLING CO. DUBAI

RECOVERY - PUMP TEST

SHA'M

DISCHARGE 103 m³/hr.

No. P1

STARTED 22.5.1977 06.10 HOURS

ORIGINAL WATER LEVEL: 19.65 metres

COMPLETED 22.5.1977 11.10 HOURS

TION OF TEST 5 HOURS

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
19.80	210	19.77	1020	
19.80	240	19.77 P2 Started	1050	
19.80	270	19.77	1080	
19.80	300	19.77	1110	
19.80	330		1140	
19.80	360		1170	
19.80	390		1200	
19.80	420		1230	
19.80	450		1260	
19.80	480		1290	
19.80	510		1320	
19.80	540		1350	
19.80	570		1380	
19.80	600		1410	
19.80	630		1440	
19.80	660			
19.79	690			
19.79	720			
19.79	750			
19.79	780			
19.79	810			
19.79 P3 Started	840			
19.78	870			
19.78	900			
19.78	930			
19.78	960			
19.78	990			
19.77				
19.77				
19.77				
19.77				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

STEP-DRAWDOWN TEST (1)

Site:	Sha'm
Well No.:	Piezometric P6
Date and Time Started:	20.5.1977 00.45 hours
Date and Time Completed:	20.5.1977 10.45 hours
Duration:	8 hours
Discharge:	30.6 m^3/hr.
Static Water Level:	19.8 metres (ground level)
Amount of Casing above ground level:	1.00 metres

PUMP TEST
STEP-DRAWDOWN TEST (1)

SITE	SHA'H	DISCHARGE	30.6 m³/hr.
WELL No.	PIEZOMETRIC P6	S.W.L.	19.8 metres (ground level)
DATE STARTED	20.5.1977 03.45 HOURS		
DATE COMPLETED	20.5.1977 10.45 HOURS		
DURATION OF TEST	2 HOURS		

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	20.80	210		1020	
1		240		1050	
2		270		1080	
3		300		1110	
4		330		1140	
5		360		1170	
6		390		1200	
7		420		1230	
8		450		1260	
9		480		1290	
10		510		1320	
12		540		1350	
14		570		1380	
16		600		1410	
18		630		1440	
20		660			
25		690			
30		720			
35		750			
40	20.89	780			
45	20.89	810			
50	20.89	840			
55	20.89	870			
60	20.89	900			
70	20.89	930			
80	20.89	960			
90	20.89	990			
100	20.89				
110	20.89				
120	20.89				
150					
180					

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. 07543/UP/1

STEP-DRAWDOWN TEST (2)

Site:	Sha'm
Well No.:	Piezometric P6
Date and Time Started:	20.5.1977 10.45 hours
Date and Time Completed:	20.5.1977 12.45 hours
Duration:	2 hours
Discharge:	63.3 m^3/hr.
Static Water Level:	19.8 metres (ground level)
Amount of Casing above ground level:	1.09 metres

PUMP TEST

STEP-DRAWDOWN TEST (2)

No.	SHA'II PIEZOMETRIC P6	DISCHARGE	62.3 m^3/hr.
STARTED	20.5.1977 10.45 HOURS	S.W.L.	19.8 metres (ground level)
COMPLETED	20.5.1977 12.45 HOURS		
TION OF TEST	2 HOURS		

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
20.89	210		1020	
20.89	240		1050	
20.90	270		1080	
20.90	300		1110	
20.91	330		1140	
20.92	360		1170	
20.93	390		1200	
20.94	420		1230	
20.94	450		1260	
20.94	480		1290	
20.95	510		1320	
20.95	540		1350	
20.95	570		1380	
20.95	600		1410	
20.95	630		1440	
20.95	660			
20.95	690			
20.95	720			
20.95	750			
20.95	780			
20.95	810			
20.95	840			
20.95	870			
20.95	900			
20.95	930			
20.96	960			
20.96	990			
20.96				
20.96				
20.96				

RECOVERY IN MINS

GOVERNMENT OF RAS AL KHAYMAH - CONTRACT NO. C 7[illegible]/[illegible]/1

STEP-DRAWDOWN TEST (3)

Site:	Sha'm
Well No.:	Piezometric P6
Date and Time Started:	20.5.1977 12.45 hours
Date and Time Completed:	20.5.1977 14.45 hours
Duration:	2 hours
Discharge:	100 m^3/hr.
Static Water Level:	
Amount of Casing above ground level:	1.00 metres

PUMP TEST

STEP-DRAWDOWN TEST (3)

SHA'M

No. PIEZOMETRIC P6

DISCHARGE 100 m^3/hr.

S.W.L.

STARTED 20.5.1977 12.45 HOURS

COMPLETED 20.5.1977 14.45 HOURS

ATION OF TEST 2 HOURS

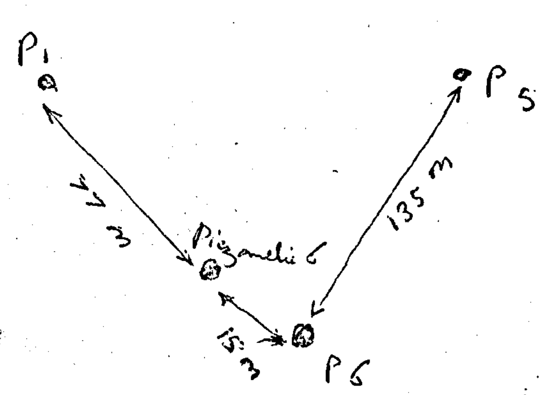
WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
20.96	210		1020	
20.96	240		1050	
20.97	270		1080	
20.97	300		1110	
21.00	330		1140	
21.03	360		1170	
21.09	390		1200	
21.09	420		1230	
21.10	450		1260	
21.10	480		1290	
21.10	510		1320	
21.10	540		1350	
21.10	570		1380	
21.10	600		1410	
21.10	630		1440	
21.10	660			
21.10	690			
21.10	720			
21.10	750			
21.10	780			
21.10	810			
21.10	840			
21.10	870			
21.10	900			
21.10	930			
21.11	960			
21.11	990			
21.11				
21.11				
21.11				

RECOVERY IN MINS

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7949/WT/1

STEP-DRAWDOWN TEST (1)

Site:	Sha'm
Well No.:	P6
Date and Time Started:	20.5.1977 08.45 hours
Date and Time Completed:	20.5.1977 10.45 hours
Duration:	2 hours
Discharge:	30.6 m^3/hr.
Static Water Level:	20 metres (ground level)
Amount of Casing above ground level:	0.59 metres
Water Temperature:	36°C
Atmospheric Temperature:	29°C
Water Samples Taken:	2 Nos. (Colour of Container: Red)



Distances

P6 to Piezometric 6 (observer) = 15 m

Piez. 6 to P1 = 77 mrs

P6 to P5 = 135 mrs

NATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

STEP-DRAWDOWN TEST (1)

291

SHA'M

P6

DISCHARGE 30.6 m^3/hr.

S.W.L. 20 metres (ground level)

TED 20.5.1977 08.45 HOURS

PLETED 20.5.1977 10.45 HOURS

OF TEST 2 HOURS

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
20.59	210		1020	
	240		1050	
	270		1080	
	300		1110	
	330		1140	
	360		1170	
	390		1200	
	420		1230	
	450		1260	
	480		1290	
	510		1320	
	540		1350	
	570		1380	
	600		1410	
	630		1440	
	660			
	690			
	720			
	750			
21.61	780			
21.64	810			
21.62	840			
21.61	870			
21.61	900			
21.61	930			
21.60	960			
21.60	990			
21.56				
21.56				
21.56				

21·56
20·59
0·97

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7542/ET/1

STEP-DRAWDOWN TEST (2)

Site:	Sha'm
Well No.:	P6
Date and Time Started:	20.5.1977 10.45 hours
Date and Time Completed:	20.5.1977 12.45 hours
Duration:	2 hours
Discharge:	62.3 m^3/hr.
Static Water Level:	20 metres (ground level)
Amount of Casing above Ground level:	0.59 metres
Water Temperature:	36°C
Atmospheric Temperature:	29°C
Water Samples Taken:	2 Nos. (Colour of Container: Green)

INTERNATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

293

STEP-DRAWDOWN TEST (2)

SITE	SHA'H	DISCHARGE	62.3 m^3/hr.
WELL No.	P6	S.W.L.	20 metres (ground level)
DATE STARTED	20.5.1977 10.45 HOURS		
DATE COMPLETED	20.5.1977 12.45 HOURS		
DURATION OF TEST	2 HOURS		

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	21.56	210		1020	
1	22.00	240		1050	
2	22.05	270		1080	
3	22.89	300		1110	
4	22.91	330		1140	
5	22.93	360		1170	
6	22.95	390		1200	
7	22.95	420		1230	
8	22.97	450		1260	
9	22.97	480		1290	
10	22.98	510		1320	
12	22.98	540		1350	
14	22.97	570		1380	
16	22.95	600		1410	
18	22.94	630		1440	
20	22.95	660			
25	22.96	690			
30	22.95	720			
35	22.97	750			
40	22.97	780			
45	22.98	810			
50	22.98	840			
55	22.97	870			
60	22.96	900			
70	22.95	930			
80	22.95	960			
90	22.97	990			
100	22.96				
110	22.98				
120	22.98				
150					

22.98
21.56
1.42

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7542/HT/1

STEP-DRAWDOWN TEST (3)

Site:	Sha'm
Well No.	P6
Date and time Started:	20.5.1977 12.45 hours
Date and time Completed:	20.5.1977 14.45 hours
Duration:	2 hrs.
Discharge:	100 m^3/hr.
Static Water Level:	20 metres (ground level)
Amount of Casing above ground level:	0.59 metres
Water Temperature:	36°C
Atmospheric Temperature:	29°C
Water Samples Taken:	2 Nos. (Colour of Container: Blue)

RNATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

STEP-DRAWDOWN TEST (3)

	SHA'H		DISCHARGE	100 m^3/hr.
O.	P6			
ARTED	20.5.1977	12.45 HOURS	S.W.L.	20 metres (ground level)
OMPLETED	20.5.1977	14.45 HOURS		
ON OF TEST	2 HOURS			

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
22.98	210		1020	
27.68	240		1050	
27.72	270		1080	
27.73	300		1110	
27.73	330		1140	
27.73	360		1170	
27.74	390		1200	
27.75	420		1230	
27.76	450		1260	
27.76	480		1290	
27.76	510		1320	
27.77	540		1350	
27.77	570		1380	
27.73	600		1410	
27.77	630		1440	
27.76	660			
27.77	690			
27.75	720			
27.76	750			
27.76	780			
27.76	810			
27.75	840			
27.74	870			
27.75	900			
27.73	930			
27.77	960			
27.76	990			
27.77				
27.76				
27.76				

$$\begin{array}{r} 27.76 \\ 22.98 \\ \hline 4.78 \end{array}$$

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. C 7543/ST/1

CONSTANT RATE PUMPING TEST

Site:	Sha'm
Well No.:	P6 (Discharge Well)
Date and Time Started:	21.5.1977 09.00 hours
Date and Time Completed:	22.5.1977 06.10 hours
Duration:	21 hours
Discharge:	104 m^3/hr.
Drawdown:	4.49 m
Static Water Level:	20 metres (ground level)
Amount of Casing above Ground level:	0.59 metres
Water Temperature:	36°C
Atmospheric Temperature:	
Water Samples Taken:	1. - 2 Nos. (Colour of Container: blue)
	2. - 2 Nos. (Colour of Container: red)
	3. - 2 Nos. (Colour of Container: yellow)
	4. - 2 Nos. (Colour of Container: green)
	5. - 2 Nos. (Colour of Container: with yellow tape)

NATIONAL WATER WELL DRILLING CO. DUBAI

CONSTANT RATE - PUMP TEST

SHA'M

: P6 (DISCHARGE WELL)

DISCHARGE 104 m^3/hr.

S.W.L. 20 metres (ground level)

ARTED 21.5.1977 09.00 HOURS

OMPLETED 22.5.1977 06.10 HOURS

N OF TEST 21 HOURS

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
20.59	210	26.16	1020	25.19
27.25	240	26.11	1050	25.14
27.23	270	26.10 Pumping started at P2 & P3	1080	25.14
27.22	300	26.03 (W.S.2)	1110	25.15
27.23	330	26.14	1140	25.15
27.23	360	26.11	1170	25.11
27.23	390	26.14	1200	25.03
27.20	420	26.14	1230	25.00
27.19	450	26.15	1260	25.03 (W.S.5)
27.18	480	26.17	1290	
27.18	510	26.15	1320	
27.13	540	26.15	1350	
26.83	570	26.18	1380	
26.70	600	26.18	1410	
26.75	630	26.18 (W.S.3)	1440	
26.72	660	26.18		
26.53	690	Motor stopped P2 & P3 stopped		(W.D. W.S. = Water Sample)
26.56 (W.S.1)	720	25.30		
26.55	750	25.33		
26.53	780	25.38		
26.45	810	25.33		
26.40	840	25.33		
26.34	870	25.38		
26.34	900	25.38 (W.S. 4)		
26.34	930	25.30		
26.33	960	25.10		
26.33	990	25.13		
26.32				
26.41				
26.41				
26.30				

RECOVERY IN MINS

ERNMENT OF RAS AL KHAIMAH - CONTRACT NO. C 7549/WT/1

COVERY TEST

ite:	Sha'm
ell No.:	P6 (Discharge Well)
ate and Time Started:	22.5.1977 05.20 hours
ate and Time Completed:	22.5.1977 11.10 hours
uration:	5 hours
ischarge:	104 m^3/hr.
riginal Water Level:	20.59 m
nrecovered Depletion:	0.10 m
Amount of Casing above Ground level:	0.59 metres
Height of Concrete Slab from ground level:	0.21 metres

NATIONAL WATER WELL DRILLING CO. DUBAI

RECOVERY - PUMP TEST

SHA'M

P6 (DISCHARGE WELL)

DISCHARGE 10½ m³/hr.

ORIGINAL WATER LEVEL: 20.59 metres

...RTED 22.5.1977 05.20 HOURS

...MPLETED 22.5.1977 11.10 HOURS

...N OF TEST 5.00 HOURS

WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
25.03	210	20.69	1020	
20.78	240	20.69 P2	1050	
20.76	270	20.69 Started	1080	
20.75	300	20.69	1110	
20.75	330		1140	
20.76	360		1170	
20.77	390		1200	
20.75	420		1230	
20.74	450		1260	
20.74	480		1290	
20.75	510		1320	
20.74	540		1350	
20.74	570		1380	
20.74	600		1410	
20.74	630		1440	
20.74	660			
20.74	690			
20.73	720			
20.73	750			
20.73	780			
20.72	810			
20.72 P3 Started	840			
20.72	870			
20.72	900			
20.71	930			
20.71	960			
20.70	990			
20.70				
20.70				
20.70				
20.70				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

CONSTANT RATE PUMPING TEST

Site:	Sayha Al Fahlayn
Well No.:	G5 (Discharge Well)
Date and Time Started:	1.6.1977 09.00 hours
Date and Time Completed:	2.6.1977 06.00 hours
Duration:	21 hours
Discharge:	86 m^3/hr. (23.9 l/s)
	71.6 m^3hr. (19.9 l/s)
Static Water Level:	23.41 metres (ground level)
Amount of Casing above ground level	0.54 metres
Water Samples Taken:	1. - Nos. (Colour of Container: Yellow)
	Water Temperature:
	Atmospheric Temperature:
	2. - Nos. (Colour of Container: Blue)
	Water Temperature: 34°C
	Atmospheric Temperature: 32°C
	3. - Nos. (Colour of Container: Green)
	Water Temperature: 34°C
	Atmospheric Temperature: 30°C
	4. - Nos. (Colour of Container: Red)
	Water Temperature: 34°C
	Atmospheric Temperature: 25°C

TERNATIONAL WATER WELL DRILLING CO. DUBAI

CONSTANT RATE - PUMP TEST

	SAYHA AL FAHLAYN	DISCHARGE	86 m^3/hr. (23.9 l/s)
L No.	G5 (Discharge Well)		71.6 m^3/hr. (19.9 l/
E STARTED	1.6.1977 09.00 HOURS		
E COMPLETED	2.6.1977 06.00 HOURS	S.W.L.	23.41 metres (ground level)
ATION OF TEST	21 HOURS		

S	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
	23.98 (W.S.1)	210	28.75	1020	
	31.64	240	28.79	1050	28.97
	31.16	270	28.80	1080	28.98
	32.23	300	28.80 (W.S.2)	1110	29.00
	32.54	330	28.81	1140	29.01
	32.63	360	28.81	1170	29.02
	32.67	390	28.82	1200	29.03
	32.72	420	28.84	1230	29.02
	32.75	450	28.86	1260	28.61
	32.75	480	28.87	1290	28.61 (W.S.4)
	32.77	510	28.86	1320	
	-	540	28.85	1350	
	32.82	570	28.87	1380	
	32.84	600	28.84 (W.S.3)	1410	
	-	630	28.85	1440	
	32.32	660	28.86		
	-	690	28.88		
	32.82	720	28.87		
	32.82	750	28.90		
	32.83	780	28.91		(N.B. W.S. =
	32.82	810	28.92		Water Sample)
	32.82	840	28.94		
	Reduced Flow Rate to 71.6 m^3/hr.	870	28.94		
	28.65	900	28.96		
	28.66	930	28.98		
	28.64	960	29.00		
	28.64	990	29.01		
	28.64				
	28.64				
	28.65				
	28.69				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

CONSTANT RATE PUMPING TEST

Site:	Sayha Al Fahlayn
Well No.:	Piezometric G5
Date and Time Started:	1.6.1977 09.00 hours
Date and Time Completed:	2.6.1977 06.00 hours
Duration:	21 hours
Discharge:	86 m^3/hr.
	71.6 m^3/hr.
Static Water Level:	23.42 metres (ground level)
Amount of Casing above ground level:	0.88 metres

INTERNATIONAL WATER WELL DRILLING CO. DUBAI

CONSTANT RATE - PUMP TEST

303

SITE	SAYHA AL FAHLAYN	DISCHARGE	86 m^3/hr.
WELL No.	PIEZOMETRIC G5		71.6 m^3/hr.
DATE STARTED	1.6.1977 09.00 HOURS		
DATE COMPLETED	2.6.1977 06.00 HOURS	S.W.L.	23.42 metres (ground level)
DURATION OF TEST	21 HOURS		

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	24.32	210	24.80	1020	24.93
1	24.50	240	24.81	1050	24.93
2	24.63	270	24.82	1080	24.93
3	24.64	300	24.83	1110	24.94
4	24.65	330	24.84	1140	24.94
5	24.66	360	24.84	1170	24.94
6	24.67	390	24.85	1200	24.95
7	24.67	420	24.86	1230	24.93
8	24.67	450	24.86	1260	24.93
9	24.68	480	24.87	1290	
10	24.68	510	24.87	1320	
12	24.69	540	24.88	1350	
14	24.69	570	24.88	1380	
16	24.70	600	24.89	1410	
18	24.70	630	24.89	1440	
20	24.71	660	24.89		
25	24.72	690	24.90		
30	24.73	720	24.90		
35	24.74	750	24.90		
40	24.75	780	24.91		
45	24.76	810	24.91		
50	24.76	840	24.91		
55	24.77	870	24.92		
60	Reduced Flow Rate to 71.6 m^3/hr.	900	24.92		
70	24.72	930	24.92		
80	24.73	960	24.92		
90	24.73	990	24.93		
100	24.74				
110	24.74				
120	24.75				
150	24.77				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

CONSTANT RATE PUMPING TEST

Site:	Sayha Al Fahlayn	
Well No.:	G6	
Date and Time Started:	1.6.1977	09.00 hours
Date and Time Completed:	2.6.1977	06.00 hours
Duration:	21 hours	
Discharge:	86 m^3/hr.	09.00 to 10.00 hours
	71.6 m^3/hr.	from 10.00 hours
Static Water Level:	22.75 metres (ground level)	
Amount of Casing above ground level:	0.40 metres	

INTERNATIONAL WATER WELL DRILLING CO. DUBAI

CONSTANT RATE - PUMP TEST

ITE: SAYHA AL FAHLAYN

ELL No.: G6

ATE STARTED: 1.6.1977 09.00 HOURS

ATE COMPLETED: 2.6.1977 06.00 HOURS

URATION OF TEST: 21 HOURS

DISCHARGE: 86 m^3/hr.
71.6 m^3/hr.

S.W.L.: 22.75 metres (ground level)

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	23.15	210	23.15	1020	23.20
1	23.15	240	23.15	1050	23.20
2	23.15	270	23.15	1080	23.20
3	23.15	300	23.16	1110	23.21
4	23.15	330	23.16	1140	23.21
5	23.15	360	23.16	1170	23.21
6	23.15	390	23.16	1200	23.21
7	23.15	420	23.16	1230	23.21
8	23.15	450	23.17	1260	23.21
9	23.15	480	23.17	1290	
10	23.15	510	23.17	1320	
12	23.15	540	23.17	1350	
14	23.15	570	23.18	1380	
16	23.15	600	23.18	1410	
18	23.15	630	23.18	1440	
20	23.15	660	23.18		
25	23.15	690	23.18		
30	23.15	720	23.18		
35	23.15	750	23.18		
40	23.15	780	23.19		
45	23.15	810	23.19		
50	23.15	840	23.19		
55	23.15	870	23.19		
60	23.15	900	23.19		
70	23.15	930	23.19		
80	23.15	960	23.20		
90	23.15	990	23.20		
100	23.15				
110	23.15				
120	23.15				
150	23.15				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/KT/1

CONSTANT RATE PUMPING TEST

Site:	Sayha Al Fahlayn
Well No.:	G2
Date and Time Started:	1.6.1977 09.00 hours
Date and Time Completed:	1.6.1977 15.00 hours
Duration:	6 hours
Discharge:	86 m^3/hr.
	71.6 m^3/hr.
Static Water Level:	25.18 metres (ground level)
Amount of Casing above ground level	0.35 metres

NTERNATIONAL WATER WELL DRILLING CO. DUBAI

CONSTANT RATE - PUMP TEST

TE	SAYHA AL FAHLAYN	DISCHARGE	86 m^3/hr.
LL No.	G2		71.6 m^3/hr.
TE STARTED	1.6.1977 09.00 HOURS		
TE COMPLETED	1.6.1977 15.00 HOURS	S.W.L.	25.18 metres (ground level)
RATION OF TEST	6 HOURS		

INS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	25.73	210	25.73	1020	
1	25.73	240	25.73	1050	
2	25.73	270	25.73	1080	
3	25.73	300	25.73	1110	
4	25.73	330	25.73	1140	
5	25.73	360	25.73	1170	
6	25.73	390	Pumping commenced at 15.15 hours for farmers	1200	
7	25.73	420		1230	
8	25.73	450		1260	
9	25.73	480		1290	
10	25.73	510		1320	
12	25.73	540		1350	
14	25.73	570		1380	
16	25.73	600		1410	
18	25.73	630		1440	
20	25.73	660			
25	25.73	690			
30	25.73	720			
35	25.73	750			
40	25.73	780			
45	25.73	810			
50	25.73	840			
55	25.73	870			
60	Reduced Flow Rate to 71.6 m^3/hr.	900			
70	25.73	930			
80	25.73	960			
90	25.73	990			
00	25.73				
10	25.73				
20	25.73				
50	25.73				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

RECOVERY TEST

Site:	Sayha Al Fahlayn
Well No.:	G5
Date and Time Started:	2.6.1977 06.10 hours
Date and Time Completed:	2.6.1977 17.40 hours
Duration:	11.30 hours
Discharge:	
Static Water Level:	23.98 metres
Amount of Casing above ground level:	0.54 metres
Height of Concrete Slab from ground level:	0.27 metres

ERNATIONAL WATER WELL DRILLING CO. DUBAI

RECOVERY - PUMP TEST

SAYHA AL FAHLAYN

DISCHARGE

. No. 05

STARTED 2.6.1977 06.10 HOURS S.W.L. 23.98 metres

COMPLETED 2.6.1977 17.40 HOURS

ATION OF TEST 11.30 HOURS

S	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
	28.61	210	24.10	1020	
	24.45	240	24.10	1050	
	24.45	270	24.10	1080	
	24.44	300	24.06	1110	
	24.43	330	24.05	1140	
	24.42	360	24.05	1170	
	24.40	390	24.05	1200	
	24.39	420	Running the Vertical Pumps	1230	
	24.38	450		1260	
	24.37	480	24.05	1290	
	24.36	510	24.05	1320	
	24.34	540	24.05	1350	
	24.34	570	24.01	1380	
	24.32	600	24.01	1410	
	24.31	630	24.01	1440	
	24.31	660	23.99		
	24.29	690	23.98		
	24.28	720			
	24.26	750			
	24.26	780			
	24.25	810			
	24.24	840			
	24.23	870			
	24.23	900			
	24.21	930			
	24.21	960			
	24.18	990			
	24.17				
	24.16				
	24.16				

RECOVERY IN MINS

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7343/WT/1

RECOVERY TEST

Site:	Sayha Al Fahlayn
Well No.:	Piezometric G5
Date and Time Started:	2.6.1977 06.10 hours
Date and Time Completed:	2.6.1977 18.40 hours
Duration:	12.30 hours
Discharge:	
Static Water Level:	24.32 metres (top casing)
Amount of Casing above ground level:	0.88 metres

INTERNATIONAL WATER WELL DRILLING CO. DUBAI

RECOVERY - PUMP TEST

SITE SAYHA AL FAHLAYN

DISCHARGE ....

WELL No. PIEZOMETRIC G5

DATE STARTED 2.6.1977 06.10 HOURS

S.W.L. 24.32 metres (top casing)

DATE COMPLETED 2.6.1977 18.40 HOURS

DURATION OF TEST 12.30 HOURS

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	24.93	210	24.47	1020	
1	24.81	240	24.47	1050	
2	24.78	270	24.46	1080	
3	24.77	300	24.44	1110	
4	24.76	330	24.44	1140	
5	24.75	360	24.43	1170	
6	24.74	390	24.43	1200	
7	24.73	420	24.43	1230	
8	24.72	450	24.41	1260	
9	24.72	480	24.41	1290	
10	24.71	510	24.41	1320	
12	24.70	540	24.40	1350	
14	24.70	570	24.40	1380	
16	24.69	600	24.40	1410	
18	24.69	630	24.40	1440	
20	24.67	660	24.39		
25	24.66	690	24.37		
30	24.65	720	24.36		
35	24.63	750	24.32		
40	24.62	780			
45	24.61	810			
50	24.60	840			
55	24.60	870			
60	24.59	900			
70	24.57	930			
80	24.56	960			
90	24.55	990			
100	24.54				
110	24.53				
120	24.52				
150	24.51				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

RECOVERY TEST

Site:	Sayha Al Fahlayn
Well No.:	G6
Date and Time Started:	2.6.1977 06.10 hours
Date and Time Completed:	2.6.1977 18.10 hours
Duration:	12 hours
Discharge:	
Static Water Level:	23.15 metres (top casing)
Amount of Casing above ground level:	0.35 metres

NTERNATIONAL WATER WELL DRILLING CO. DUBAI

RECOVERY - PUMP TEST 313

TE	SAYHA AL FAHLAYN	DISCHARGE	
ELL No.	G6		
ATE STARTED	2.6.1977 06.10 HOURS	S.W.L.	23.15 metres (top casing)
ATE COMPLETED	2.6.1977 18.10 HOURS		
URATION OF TEST	12 HOURS		

INS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	23.21	210	23.20	1020	
1	23.21	240	23.20	1050	
2	23.21	270	23.20	1080	
3	23.21	300	23.20.	1110	
4	23.21	330	23.20	1140	
5	23.21	360	23.20	1170	
6	23.21	390	23.19	1200	
7	23.21	420	23.19	1230	
8	23.21	450	23.19	1260	
9	23.21	480	23.19	1290	
10	23.21	510	23.19	1320	
12	23.21	540	23.18	1350	
14	23.21	570	23.17	1380	
16	23.21	600	23.16	1410	
18	23.21	630	23.16	1440	
20	23.21	660	23.15		
25	23.21	690	23.15		
30	23.21	720	23.15		
35	23.21	750			
40	23.21	780			
45	23.21	810			
50	23.21	840			
55	23.21	870			
60	23.21	900			
70	23.21	930			
30	23.21	960			
30	23.21	990			
00	23.21				
10	23.21				
20	23.21				
50	23.21				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

STEP-DRAWDOWN TEST (1)

Site:	Sayha Al Fahlayn
Well No.:	G5
Date and Time Started:	31.5.1977 09.20 hours
Date and Time Completed	31.5.1977 11.20 hours
Duration:	2 hours
Discharge:	30.6 m^3/hr.
Static Water Level:	23.77 metres (ground level)
Amount of Casing above ground level:	0.54 metres
Water Temperature:	35°C
Atmospheric Temperature:	30°C
Water Samples Taken:	2 Nos. (Colour of Container: Red)

NTERNATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

STEP-DRAWDOWN TEST (1)

TE	SAYHA AL FAHLAYN
ELL No.	G5
ATE STARTED	31.5.1977 09.20 HOURS
ATE COMPLETED	31.5.1977 11.20 HOURS
URATION OF TEST	2 HOURS

DISCHARGE 30.6 m^3/hr.

S.W.L. 23.77 metres (ground level)

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	24.31	210		1020	
1	30.75	240		1050	
2	30.20	270		1080	
3	24.35	300		1110	
4	24.68	330		1140	
5	24.70	360		1170	
6	24.75	390		1200	
7	24.72	420		1230	
8	24.70 opened	450		1260	
9	25.09 valve	480		1290	
10	25.08	510		1320	
12	25.08	540		1350	
14	25.08	570		1380	
16	25.10	600		1410	
18	25.11	630		1440	
20	25.12	660			
25	25.12	690			
30	25.12	720			
35	25.08	750			
40	25.07	780			
45	25.08	810			
50	25.09	840			
55	25.08	870			
60	25.09	900			
70	25.08	930			
80	25.10	960			
90	25.09	990			
100	25.10				
110	25.10				
120	25.09				
150					

RECOVERY IN MINS

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/KT/1

STEP-DRAWDOWN TEST (2)

Site:	Sayha Al Fahlayn
Well No.:	C5
Date and Time Started:	31.5.1977 11.20 hours
Date and Time Completed:	31.5.1977 13.20 hours
Duration:	2 hours
Discharge:	62.4 m^3/hr.
Static Water Level:	23.77 metres (ground level)
Amount of Casing above ground level:	0.54 metres
Water Temperature:	35°C
Atmospheric Temperature:	30°C
Water Samples Taken:	2 Nos. (Colour of Container: Yellow

ITERNATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

STEP-DRAWDOWN TEST (2)

317

E	SAYHA AL FAHLAYN	DISCHARGE	62.4 m^3hr.
LL No.	G5		
TE STARTED	31.5.1977 11.20 HOURS	S.W.L.	23.77 metres (ground level)
TE COMPLETED	31.5.1977 13.20 HOURS		
RATION OF TEST	2 HOURS		

NS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
	25.09	210		1020	
	-	240		1050	
	-	270		1080	
	-	300		1110	
	27.48	330		1140	
	27.69	360		1170	
	27.68	390		1200	
	27.68	420		1230	
	27.70	450		1260	
	27.73	480		1290	
	27.69	510		1320	
	27.69	540		1350	
	27.70	570		1380	
	27.69	600		1410	
	27.72	630		1440	
	27.72	660			
	27.74	690			
	27.74	720			
	27.75	750			
	27.77	780			
	27.78	810			
	27.78	840			
	27.79	870			
	27.78	900			
	27.84	930			
	27.82	960			
	27.86	990			
	27.84				
	27.85				
	27.85				
	27.85				

RECOVERY IN MINS

الشركة العالمية لحفر الآبار

INTERNATIONAL WATER WELL DRILLING CO.

GOVERNMENT OF RAS AL KHAIMAH - CONTRACT NO. G 7543/WT/1

STEP-DRAWDOWN TEST (3)

Site:	Sayha Al Fahlayn
Well No.:	G5
Date and Time Started:	31.5.1977 13.20 hours
Date and Time Completed:	31.5.1977 15.20 hours
Duration:	2 hours
Discharge:	86 m^3/hr. (23.9 l/s)
Static Water Level:	23.77 metres (ground level)
Amount of Casing above ground level:	0.54 metres
Water Temperature:	35°C
Atmospheric Temperature:	42°C
Water Samples Taken:	2 Nos. (Colour of Container: Green)

INTERNATIONAL WATER WELL DRILLING CO. DUBAI

PUMP TEST

STEP-DRAWDOWN TEST (3)

SITE	SAYHA AL FAHLAYN
WELL No.	G5
DATE STARTED	31.5.1977 13.20 HOURS
DATE COMPLETED	31.5.1977 15.20 HOURS
DURATION OF TEST	2 HOURS

DISCHARGE 86 m^3/hr. (23.9 l/

S.W.L. 23.77 metres (ground level)

MINS	WATER LEVEL	MINS	WATER LEVEL	MINS	WATER LEVEL
0	27.85	210		1020	
1	-	240		1050	
2	-	270		1080	
3	-	300		1110	
4	-	330		1140	
5	28.30	360		1170	
6		390		1200	
7		420		1230	
8		450		1260	
9		480		1290	
10	28.81	510		1320	
12	28.82	540		1350	
14	28.82	570		1380	
16	-	600		1410	
18	28.83	630		1440	
20	28.84	660			
25	28.87	690			
30	28.89	720			
35	29.00	750			
40	29.10	780			
45	29.10	810			
50	29.10	840			
55	29.10	870			
60	29.10	900			
70	29.10	930			
80	29.09	960			
90	29.08	990			
100	29.09				
110	29.09				
120	29.09				
150					

RECOVERY IN MINS

Appendix II : Chemical analysis data of ground water samples.

Location DUNE SANDS	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
T. Yikaisa 03843 28075	2.4.67	2200 2328	1508	8·42	484	250	37·5 1·87 7·98	95 7·81 33·32	310 13·49 57·55	10·5 0·27 1.15	23·44	nil	305 5·00 20·05	300 6·25 25·06	480 13·54 54·29	7·7 0·12 0·48	0·6 0·03 0·12	24·94	0·1	0·02	0·56
T. Adhieb 0364- 2823	2.7.68	7000 8113	5638	7·8	1380	155	130 6·49 7·24	255 20·97 23·41	1387 60·33 67·35	70 1·79 2·00	89·58	nil	189 3·10 3·47	672 13·99 17·55	2559 72·16 80·81	2.4 0·04 0·05	0·25 0·01 0·01	89·30	0·1	nil	0·36
T. Marraghan 0361- 2818-	1.7.68	5700 6251	4308	7·6	612	280	72 3·59 5·79	104·5 6·59 10·63	1173 51·03 82·33	30 0·77 1·24	61·98	nil	341·6 5·60 8·77	470 9·79 15·34	1716 48·39 75·80	3·6 0·06 0·09	0·08 Tr Tr	63·84	0·12	nil	0·06
T. Dabdibba 0360- 2810-	1.4.67	6050 6786	4404	8·08	734	230	70 3·49 5·30	136 11·18 16·97	1155 50·24 76·27	37·5 0·96 1·46	65·87	nil	280 4·59 6·33	875 18·22 25·14	1750 49·35 68·10	14·9 0·24 0·33	1·3 0·07 0·10	72·47	0·08	0·04	1·01
T. Asmar 03701 28108	2.4.67	3500 3378	2234	8·58	418	168	50 2·50 7·28	71 5·84 17·00	585 25·45 74.09	22 0·56 1·63	34·35	nil	205 3·36 9·15	425 8·85 24·11	860 24·25 66·06	11·9 0·19 0·52	1·2 0·06 0·16	36·71	0·67	0·04	0·27
T. Rashid 03606 28113	1.4.67	7500 7847	6590	8·35	1057	250	77 3·84 4·26	210 17·27 19·15	1560 67·86 75·24	47·5 1·22 1·35	90·19	nil	305 5·00 5·27	1410 29·36 30·92	2130 60·07 63·25	30 0·48 0·51	1·2 0·06 0·06	94·97	0·07	0·07	1·97
T. Mahadhab 03650 28126	2.4.67	2790 3258	1834	8·45	364	234	37·5 1·87 6·38	65·5 5·39 18·38	500 21·75 74·18	12 0·31 1·06	29·32	nil	285 4·67 15·15	395 8·22 26·66	620 17·48 56·70	25·9 0·42 1·36	0·8 0·04 0·13	30·83	0·37	0·02	0·26
T. Nabaybighah 03808 27959	2.7.68	1540 2050	1106	7·9	316	285	36 1·80 9·99	54·7 4·50 24·99	264·5 11·51 63·91	8 0·20 3·60	18·01	nil	347·7 5·70 31·81	139·2 2·90 16·18	329·7 9·30 51·90	<1 <0·02 0·11	0·07 Tr Tr	17·92	0·61	0·02	0·02
T. Zubair 0362- 2808-	1.4.67	5000 5686	3538	9·04	594	234	60 2·99 5·63	108 8·88 16·72	925 40·24 75·75	39·5 1·01 1·90	53·12	nil	285 4·67 7·90	715 14·89 25·20	1380 38·92 65·87	34·8 0·56 0·95	1·0 0·05 0·09	59·09	0·05	0·04	0·64

2

DUNE SANDS (continued)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
T. Helewa 0362- 2811-	1.4.67	5005 5586	3506	7·95	616	230	64 3.19 5·97	110 9·05 16·94	935 40·67 76·12	20·5 0·52 0·97	53·43	nil	280 4·59 8·04	665 13·85 24·25	1370 38·63 67·64	14 0·23 0·40	0·8 0·04 0·07	57·11	0·04	0·04	0·05
T. Qaran (North) 03745 28220	2.4.67	9400 10773	7554	8·38	1972	451	169 8·43 7·27	376 30·92 26·68	1710 74·39 64·19	84 2·15 1·86	115·89	nil	550 9·01 7·45	1130 23·53 19·46	3000 84·6 69·96	230·3 3·72 3·08	1·1 0·06 0·05	120·92	0·98	0·23	1·13
Bida'at (17) 03526 27918	1.7.68	1810 1662	1650	8·0	276	170	40 2·00 10·78	42·5 3·50 18·88	299 13·01 70·13	1·4 0·04 0·22	18·55	nil	207·4 3·40 18·39	149 3·10 16·77	424 11·96 64·68	1·8 0·03 0·16	0·07 Tr Tr	18·49	0·2	nil	0·03
Lambah 03768 28168	2.7.68	1860 2022	1204	8·4	438	215	22 1·10 8·45	49·8 4·10 31·49	170·2 7·40 56·84	16·3 0·42 3·23	13·02	nil	262·3 4·30 32·95	120 2·50 19·16	220 6·20 47·51	2·4 0·04 0·31	0·13 0·01 0·08	13·05	0·19	nil	0·12
Gharhad 03450 28010	2.7.68	7150 7448	5336	8·0	631	328	64 3·19 8·73	114·2 9·39 25·70	522·6 22·73 62·21	48 1·23 3·37	36·54	nil	399·4 6·55 8·16	672 13·99 17·44	2116 59·67 74·36	1·0 0·02 0·03	0·14 0·01 0·01	80·24	0·1	nil	0·17
Riqa Hamra 03525 28057	2.7.68	6250 6650	4526	8·3	274	535	24 1·20 1·74	35·2 2·89 4·19	1472 64·03 92·91	31·3 0·80 1·16	68·92	nil	652·7 10·70 15·52	509 10·60 15·38	1687 47·57 69·01	<1·0 <0·02 0·03	0·67 0·04 0·06	68·93	0·15	nil	0·07
Sirvah 03620 28140	28.1.67	3850 4041	2554	8·02	581 581	200 200	59·7 2·98 7·48	105 8·64 21·69	640 27·84 69·90	14·5 0·37 0·93	39·83	nil	244 4·0 9·50	557 11·60 27·54	925 26·09 61·94	24·5 0·40 0·95	0·6 0·03 0·07	42·12	0·05	nil	0·3
near Libsah 03748 28136	2.4.67	5900 6384	4304	8·72	698	270	66·5 3·32 5·18	128 10·53 16·42	1140 49·59 77.33	27 0·69 1·08	64·13	nil	330 5·41 8·09	575 11·97 17·90	1750 49·35 73·80	6·2 0·10 0·15	0·8 0·04 0·06	66·87	2·9	0·21	0·69
Sayh Biyatah 03777 28130	2.4.67	5000 5686	3644	8·14	670	226	70 3·49 6·51	120 9·87 18·40	910 39·59 73·81	27 0·69 1·29	53·64	7·5 0·25 0·42	260 4·26 7·11	635 13·22 22·07	1490 42·02 70·14	7·5 0·12 0·20	0·8 0·04 0·07	59·91	0·66	0·11	0·70
Lamhah 03769 28168	5.5.66	1050 950	622	7·9	180	270	43 2·15 20·59	17 1·40 13·41	150 6·53 62·55	14 0·36 3·45	10·44	162 5·40 53·73	- -	61 1·27 12·64	120 3·38 33·63	- -	- -	10·05	-	-	-

Location GRAVEL PLAIN (NORTH)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
Salihiyah 03987 28458	5.12.66	4900 5120	3330	8·22	618	202	114·6 5·72 11·15	80·6 6·63 12·92	886 38·54 75·10	16·8 0·43 0·84	51·32	nil	246 4·03 7·74	420 8·74 16·79	1377 38·83 74·62	25·0 0·40 0·77	0·7 0·04 0·08	52·04 100·0	0·1	nil	0·23
Uraybi 03975 28526	5.12.66	9000 7315	5912	7·73	1313	197	254·6 12·70 12·77	164·6 13·54 13·62	1667 72·51 72·90	27·8 0·71 0·71	99·46	nil	240 3·93 3·95	629 13·10 13·16	2918 82·29 82·65	12·0 0·19 0·19	0·8 0·05 0·05	99·56 100·0	0·12	nil	0·41
Digdaga No.5 03973 28389	11.10.66	5050 3857	3129	7·10	571	275	92·4 4·61 8·88	82·5 6·78 13·05	920 40·02 77·05	20·7 0·53 1·02	51·94	nil	336 5·51 10·56	519 10·81 20·72	1266 35·70 68·43	- - -	2·8 0·15 0·29	52·17 100·0	0·16	nil	0·56
Haramil 03930 28298	1.4.67	166 1796	1080	8·65	336	172	49·0 2·45 14·28	52·0 4·28 24·94	235 10·22 59·56	8·0 0·21 1·22	17·16	nil	210 3·44 18·92	200 4·16 22·88	370 10·43 57·37	7·4 0·12 0·66	0·5 0·03 0·17	18.18 100·0	0·18	0·011	0·29
Tawi Jahili 03925 28222	2.4.67	1275 1397	824	8·4	200	176	25·5 1·27 10·76	33·0 2·71 22·97	175 7·61 64·49	8·0 0·21 1·78	11·80	nil	215 3·52 25·21	180 3·75 26·86	225 6·35 45·49	19·9 0·32 2·29	0·4 0·02 0·14	13·96 99·99	0·20	0·016	0·24
Tawi Sa'idi 03900 28228	11.10.66	2680 1862	525	7·83	310	235	18·6 0·93 3·57	63·9 5·26 20.17	452 19·66 75·38	9·0 0·23 0·88	26·08	nil	286 4·69 17·84	413 8·60 32·71	461 13·00 49·45	- -	Tr -	26·29 100·0	0·04	0·052	0·03
Khatt (North) 04006 28332	11.10.66	2390 1862	1441	7·1	366	205	85·2 4·25 17·14	36·9 3·03 12·22	396 17·23 69·50	10·9 0·28 1·13	24·79	nil	250 4·10 16·55	245 5·10 20·58	550 15·51 62·59	- -	1·3 0·07 0·28	24·78 100·0	0·39	0·041	0·27
Khatt (South) 04006 28330	11.10.66	2300 1796	1404	7·2	359	209	85·6 4·27 16·76	35·0 2·88 11·30	416 18·10 71·04	9·0 0·23 0·90	25·48	nil	255 4·18 16·46	283 5·89 23·20	540 15·23 59·98	- - -	1·7 0·09 0·35	25·39 99·99	0·11	nil	0·39
Khatt (South) 04006 28330	Nov.1975	±3000	1519 1394	7·4 7·5			84·8 4·23 18·08	32·1 2·64 11·29	375·1 16·32 69·77	7·95 0·20 0·86	23·39	-	248·3 4·07 17.4	192·2 4·00 17·1	541·9 15·28 65·33	- - -	0·73 0·04 0·17	23·39 100·0	0·08		-

GRAVEL PLAIN (NORTH) (continued)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
Kuways 03967 28505	5.12.66	9600 7647	6216	7·93	1329	165	261·7 13·06 12·49	164·1 13·50 12·92	1777 77·30 73·95	26·2 0·67 0·64	104·53	nil	201 3·29 3·13	624 12·99 12·37	3145 88·69 84·43	0·9 0·01 0·01	1·3 0·07 0·07	105·05 100·0	0·12	nil	0·43
Bida 03971 28483	5.12.66	8400 6849	5774	8·2	1322	164	256·1 12·78 13·97	165·9 13·64 14·91	1480 64·38 70·37	27·0 0·69 0·75	91·49	3·0 0·10 0·11	194 3·18 3·48	513 10·68 11·70	2732 77·04 84·4	15·0 0·24 0·26	0·7 0·04 0·04	91·28 99·99	0·17	nil	0·40
T. Hamramiyah 03907 28331	28.2.67	2280 2309	1381	8·0	354	274	40·7 2·03 9·00	61·3 5·04 22·34	340 14·79 65·56	27·3 0·70 3·10	22·56	nil -	335 5·49 22·11	280 5·83 23·48	429 12·10 48·73	85·5 1·38 5·56	0·6 0·03 0·12	24·83 100·0	0·18	nil	0·29
T. Hudaythah 03895 28307	2.4.67	2430 2527	1624	9·3	472	337	60·5 3·02 12·03	78·0 6·41 25·53	350 15·23 60·65	17·5 0·45 1·79	25·11	30·0 1·00 3·59	350 5·74 20·6	290 6·04 21·68	530 14·95 53·66	6·3 0·10 0·36	0·5 0·03 0·11	27·86 100·0	0·13	0·13	0·13
Shimal 04021 28553	24.11.66	2900 2327	1638	8·4	465	219	86·6 4·32 13·99	60·3 4·96 16·06	491 21·36 69·17	9·4 0·24 0·78	30·88	3.0 0·10 0·31	260 4·26 13·39	364 7·58 23·83	681 19·20 60·36	39·0 0·63 1·98	0·7 0·04 0·13	31·81 100·0	0·3	0·02	0·20
Ghubb 03991 28546	24.11.66	3700 2979	2412	8·1	541	190	109·4 5·46 14·23	64·9 5·34 13·92	600 26·1 68·04	57·1 1·46 3·81	38·36	nil - -	232 3·80 10·0	295 6·14 16·16	994 28·03 73·76	- - -	0·5 0·03 0·08	38·00 100·0	0·24	nil	0·24
T. Jalijilah 03899 28264	11.10.66	1260 1064	838	7·95	283	220	30·8 1·54 10·50	49·8 4·10 27·93	203 8·83 60·15	8·2 0·21 1·43	14·68	nil	268 4·39 29·97	172 3·58 24·44	237 6·68 45·60	- -	Tr -	14·65	0·08	0·03	0·13
T. Hurayjah 03840 28308	2.4.67	3950 4256	2648	8·01	383	230	52·5 2·62 6·40	61·0 5·02 12·26	750 32·63 79·70	26 0·67 1·64	40·94	nil	280 4.59 10·71	515 10·72 25·01	970 27·35 63·80	9·1 0·15 0·35	1·1 0·06 0·14	42·87	0·76	0·03	0·58
T. Samha 03820 28273	28.2.67	5800 5748	3557	8·05	645	200	82·7 4·13 7·26	106·0 8·72 15·32	995 43·28 76·05	30·5 0·78 1·37	56·91	nil	244 4·0 6·67	624 12·99 21·66	1505 42·44 70·78	31·8 0·51 0·85	0·4 0·02 0·03	59·96	0·6	0·02	0·68

5

GRAVEL PLAIN (NORTH) (continued)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
T. Harmalah 03845 28340	2.4.67	5600 3724	2506	8·59	517	379	103 5·14 13·34	63 5·18 13·45	610 26·54 68·90	65 1·66 4·31	38·52	18 0·60 1·33	425 6·97 15·41	735 15·30 33·82	770 21·71 47·99	37·5 0·60 1·33	1·1 0·06 0·13	45·24	0·3	0·18	1·25
T. Biyalan 03899 28380	16.5.67	9700 9510	6704	8·36	1236	378	132 6·59 5·89	220 18·09 16·16	1955 85·04 75·98	86 2·20 1·97	111·92	6 0·20 0·17	448 7·34 6·40	1488 30·98 27·02	2691 75·89 66·19	- -	4·5 0·24 0·21	114·65	0·35	0·01	0·97
T. Zaid 0381 28310	11.10.66	2590 1995	1633	7·2	420	307	40·5 2·02 7·23	77·4 6·37 22·81	441 19·18 68·67	14·1 0·36 1·29	27·93	nil -	374 6·13 21·86	413 8·60 30·67	472 13·31 47·47	- -	Tr - -	28·04	0·21	0·02	0·29
Shimnal 04020 28568	24.11.66	10000 8645	7412	8·1	1327	292	187·4 9·35 7·69	208·6 17·16 14·11	2166 94·22 77·49	33·6 0·86 0·70	121·59	nil 4·71	356 5·83 21·03	1249 26·00 73·62	3228 91·03 0·59	45 0·73 0·05	1·1 0·06	123·65	0·45	nil	0·50
Ma'Yarid 03992 28557	24.11.66	10000 6650	6620	7·98	1314	243	212 10·58 9·63	190·6 15·67 14·27	1888 82·13 74·79	55·9 1·43 1·30	109·81	nil	296 4·85 4·43	682 14·20 12·96	3200 90·24 82·38	13 0·21 0·19	0·8 0·04 0·04	109·54	0·13	nil	0·33
Hudaybah 03970 28542	5.12.66	8100 6517	5380	8·1	1038	240	188·4 9·40 10·95	137·8 11·33 13·20	1480 64·38 75·01	28·1 0·72 0·84	85·83	nil	292 4·79 5·57	529 11·01 12·79	2481 69·96 81·28	17 0·27 0·31	0·7 0·04 0·05	86·07	0·8	nil	0·54
Kuways 03969 28518	5.12.66	12100 9310	7750	7·6	1739	239	355·3 17·73 14·11	206·6 16·99 13·52	2074 90·22 71·77	29·7 0·76 0·61	125·7	nil	325 5·33 4·20	736 15·32 12·08	3747 105·67 83·34	27 0·44 0·35	0·7 0·04 0·03	126·8	0·32	0·02	0·39
Al Faylayn 03980 28430	5.12.66	4350 3458	2728	8·21	531	255	89·2 4·45 9·70	74·3 6·11 13·31	800 34·8 75·83	20·7 0·53 1·15	45·89	6·0 0·20 0·43	299 4·90 10·54	462 9·62 20·70	1109 31·27 67·29	29 0·47 1·01	0·2 0·01 0·02	46·47	1·4	0·01	0·30
Hayl 03986 28430	5.12.66	2670 1995	1682	8·1	361	181	84·8 4·23 15·80	36·0 2·96 11·05	444 19·31 72·11	10·9 0·28 1·05	26·78	nil	221 3·62 13·26	211 4·39 16·05	671 18·92 69·18	24 0·39 1·43	0·6 0·03 0·22	27·35	0·5	nil	0·17

GRAVEL PLAIN (NORTH) (continued)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
T. Mathlootha 03935 28334	May '67	3000 3059	1892	7·65	480	220	70 3·49 10·67	74 6·09 18·62	524 22·79 69·69	13 0·33 1·01	32·7	nil	268 4·39 13·63	420 8·74 27·13	673 18·98 58·93	3·5 0·06 0·19	0·8 0·04 0·12	32·21	0·02	nil	0·11
T. Rashid 03964 28382	6.5.67	2600 2527	1704	8·1	122	600	25 1·25 4·03	14·5 1·19 3·84	649 28·23 91·06	13 0·33 1·06	31·0	nil	732 12·0 39·74	408 8·49 28·11	333 9·39 31·09	3·5 0·06 0·20	5·0 0·26 0·86	30·20	0·12	0·003	0·20
T. Bidiyah 03923 28403	6.5.67	8800 8775	6250	7·92	1387	214	153 7·63 7·55	244 20·07 19·87	1651 71·82 71·09	58·5 1·50 1·48	101·02	nil	262 4·29 3·83	1416 29·48 26·29	2496 70·39 62·78	37 0·60 0·54	1·4 7·37 6·57	112·13	0·31	nil	0·75
T. Hamham 03955 28408	6.5.67	6700 6780	4426	7·7	798	274	105 5·24 6·86	130 10·69 13·99	1375 59·81 78·26	26·5 0·68 0·89	76·42	nil	335 5·49 7·22	833 17·34 22·82	1875 52·88 69·59	16·5 0·27 0·36	0·1 0·01 0·01	75·99	0·12	nil	0·56
T. Harmalah 03846 28342	10.4.67	2430 2394	1502	8·15	193	185	28·5 1.42 6·75	29·5 2.43 11·54	385 16·75 79·57	17·5 0·45 2·14	21·05	nil	226 3·70 14·29	368 7·66 29·58	507 14·30 55·21	11·0 0·18 0·69	1·1 0·06 0·23	25·90	0·04	nil	0·56
Burayrat 04022 28505	2.7.68	1965 1995	1212	7·95	290	160	66 3·29 15·72	29·2 2·40 11.47	345 15·01 71·72	9 0·23 1·10	20·93	-	195·2 3·20 13·97	91·2 1·90 8·29	545·9 15·39 67·18	1·5 2·42 10·56	0·03 Tr	22·91	0·08	nil	0·03
Burayrat 04022 28505	9.7.71	2100	1380	7·9	300	165	68 3·38 14·32	32 2·62 11·10	400 17·39 73·69	7 0·19 0·81	23·6		99 3·3 13·98	125 2·6 11·02	620 17·46 73·98	6 0·09 0·38	- -	23·6	0·60	nil	-
Burayrat 04022 28505	Dec. '74	2320	1625	8·3			73 3·64 14·80	32 2·63 10·69	415 18·05 73·37	11 0·28 1·14	24·6	12 0·4 1·45	165 2·70 9·76	310 6·45 23·31	641 18·08 65·34	ND - -	0·88 0·04 0·15	27·67			-
Burayrat (4) 0422 28505	18.3.77	-					58 2·89 17·94	20·5 1·68 10·43	261 11·36 70·52	6·9 0·18 1·12	16·11	7·92 0·26 1·54	166 2·72 16·07	532 1·11 6·56	445 12·54 74·07	17·5 0·29 1·71	0·28 0·01 0·06	16·93	-	-	-

GRAVEL PLAIN (NORTH) (continued)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
Sayh Fahlayn 04005 28401	13.4.67	2290 3458	1520	8·21	350	197	82 4·09 17·85	35 2·88 12·57	360 15·66 68·32	11·5 0·29 1·27	22·92	nil	240 3·93 15·86	235 4·89 19·73	560 15·79 63·72	7·7 0·12 0·48	0·9 0·05 0·20	24·78	0·44	0·05	0·17
Sayh El Fahlayn	16.3.77						64 3·19 14·80	32·7 2·69 12·48	355 15·44 71·61	9·4 0·24 1·11	21·56	nil	188 3·07 13·58	127 2·64 11·68	591 16·65 73·67	13·5 0·22 0·97	0·42 0·02 0·09	22·6	-	-	-
Sayh Fahlayn 03993 28401	13.4.67	2400 2261	2116	8·65	692	422	203 10·13 33·10	41·5 3·41 11·14	385 16·75 54·74	12 0·31 1·01	30·60	nil	515 8·44 27·40	280 5·83 18·93	585 16·50 53·57	0·2 0·003 0·01	0·6 0·03 0·10	30·80	5·3	0·42	0·37
Hamraniyah 03926 28306	13.4.67	2500 2593	1990	11·37	652	316	150 7·49 30·50	64 5·26 21·42	260 11·31 46·05	19·5 0·50 2·04	24·56	144 4·80 20·90	92 1·51 6·57	270 5·62 24·47	385 10·86 47·28	9·9 0·16 0·70	0·3 0·02 0·09	22·97	0·7	0·73	0·34
Hamraniyah 03936 28306	13.4.67	1790 1795	1196	8·71	335	180	54 2·69 15·10	48·5 3·99 22·39	250 10·88 61·05	10 0·26 1·46	17·82	nil	220 3·61 17·82	240 5·00 24·68	410 11·56 57·06	4·0 0·06 0·30	0·6 0·03 0·15	20·26	1·06	0·04	0·37
Haremle 03823 28380	2.7.68	12400 13000	10200	8·15	1641	260	228 11·38 7·17	260 21·38 13·47	2845 123·76 78·00	84 2·15 1·36	158·67	-	317 5·20 3·28	1272 26·48 16·72	4492 126·67 79·96	1·0 0·02 1·26	0·7 0·04 0·03	158·41	0·19	nil	0·22
Sha'am	17.3.77	-	calc. 1182				74·5 3·72 20·24	33 2·71 14·74	270 11·74 63·87	8·5 0·22 1·20	18·38	- -	148 2·43 12·15	66·4 1·38 6·9	563 15·87 79·35	18·5 0·3 1·5	0·5 0·03 0·15	20·0	-	-	-
Sha'am (Cement)	15.3.77	-	calc. 1080	-			74 3·69 21·65	32·7 2·69 15·79	240 10·44 61·27	8·6 0·22 1·29	17·04	- -	167 2·72 15·32	60·1 1·25 7·04	474·8 13·38 75·34	22·7 0·37 2·08	0·32 0·02 0·11	17·76	-	-	-
W. Rahabah	15.3.77		calc. 11240	-			523 26·1 13·92	245 20·2 10·77	3200 139·2 74·24	81 2·07 1·10	187·5	- -	194 3·17 1·61	294 6·12 3·10	6607 186·3 94·47	96·5 1·56 0·79	0·57 0·03 0·02	197·2	-	-	-

Location GRAVEL PLAIN (SOUTH)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
T. Muraqibat 03892 28011	2.4.67	1130 1263	796	10·5	203	239	22·5 1·12 8·90	35·5 2·92 23·21	190 8·27 65·74	10·5 0·27 2·15	12·58	52·5 1·75 11·92	185 3·03 20·64	230 4·79 32·63	170 4·79 32·63	18·8 0·30 2·04	0·3 0·02 0·14	14·68	0·26	0·04	0·17
F. al Mu'alla 03840 28039	11.10.66	1410 1064	806	7·0	244	220	25·8 1·29 9·25	43·5 3·58 25·68	204 8·87 63·63	7·8 0·20 1·43	13·94	nil -	268 4·39 31·33	125 2·60 18·56	249 7·02 50·11	- - -	Tr - -	14·01	0·09	0·02	0·1
F. al Mu'alla 03845 28031	14.5.67	1550 1463	1011	8·0	239	275	26 1·30 9·19	42 3·45 24·38	210 9·14 64·59	10 0·26 1·84	14·15	nil -	335 5·49 35·74	78 1·62 10·55	291 8·21 53·45	1·0 0·02 0·13	0·4 0·02 0·13	15·36	1·92	0·08	0·15
Manama (TOS) 04029 28015	23.5.66	1900	1526	8·4	748	278	15 0·75 3·11	172·3 14·17 58·75	- (9·20) (38·14)	-	-	83·4 2·78 11·53	169 2·77 11·48	86 1·79 7·42	595 16·78 69·57	Tr -	Tr -	24·12	0·24	-	-
F. Manama 04016 28012	23.5.66	560	354	7·9	220	382	23·5 1·17 11·67	39·3 3·23 32·20	- (5·63) (56·13)	-	-	114·5 3·82 38·09	233 3·82 38·09	33 0·69 6·88	58 1·64 16·35	3·3 0·05 0·50	0·2 0·01 0·1	10·03	0·2	-	-
T. Huwayrah 04077 27979	11.10.66	670 525	424	7·23	239	157	17·8 0·89 12·52	47·0 3·87 54·43	52 2·26 31·79	3·5 0·09 1·27	7·11	nil -	191 3·13 44·21	38 0·79 11·16	112 3·16 44·63	- -	Tr -	7·08	0·15	0·06	0·13
T. Suhaylah 0397- 2805-	1.4.67	1310 1396	872	8·98	264	205	26·5 1·32 10·42	48·0 3·95 31·18	160 6·96 54·93	17 0·44 3·47	12·67	nil -	250 4·10 27·68	190 3·96 26·74	225 6·35 42·88	23·7 0·38 2·57	0·3 0·02 0·14	14·81	0·07	0·01	0·14
Manama 04012 28010	23.5.66	700	428	7·65	237	431	27·6 1·38 11·19	40·6 3·34 27·09	- (7·61) (61·72)	-	12·33	129·2 4·31 34·96	263 4·31 34·96	37 0·77 6·25	102 2·88 23·36	2·9 0·05 0·41	0·2 0·01 0·08	12·33	0·10	-	-
near Dhaid 03893 27957	27.11.66	470 419	392	8·12	203	132	16·2 0·81 15·52	39·5 3·25 62·26	23 1·00 19·16	6·2 0·16 3·07	5·22	nil -	161 2·64 48·26	33 0·69 12·61	69 1·95 35·65	12·0 0·19 3·47	Tr -	5·47	0·18	0·004	0·16

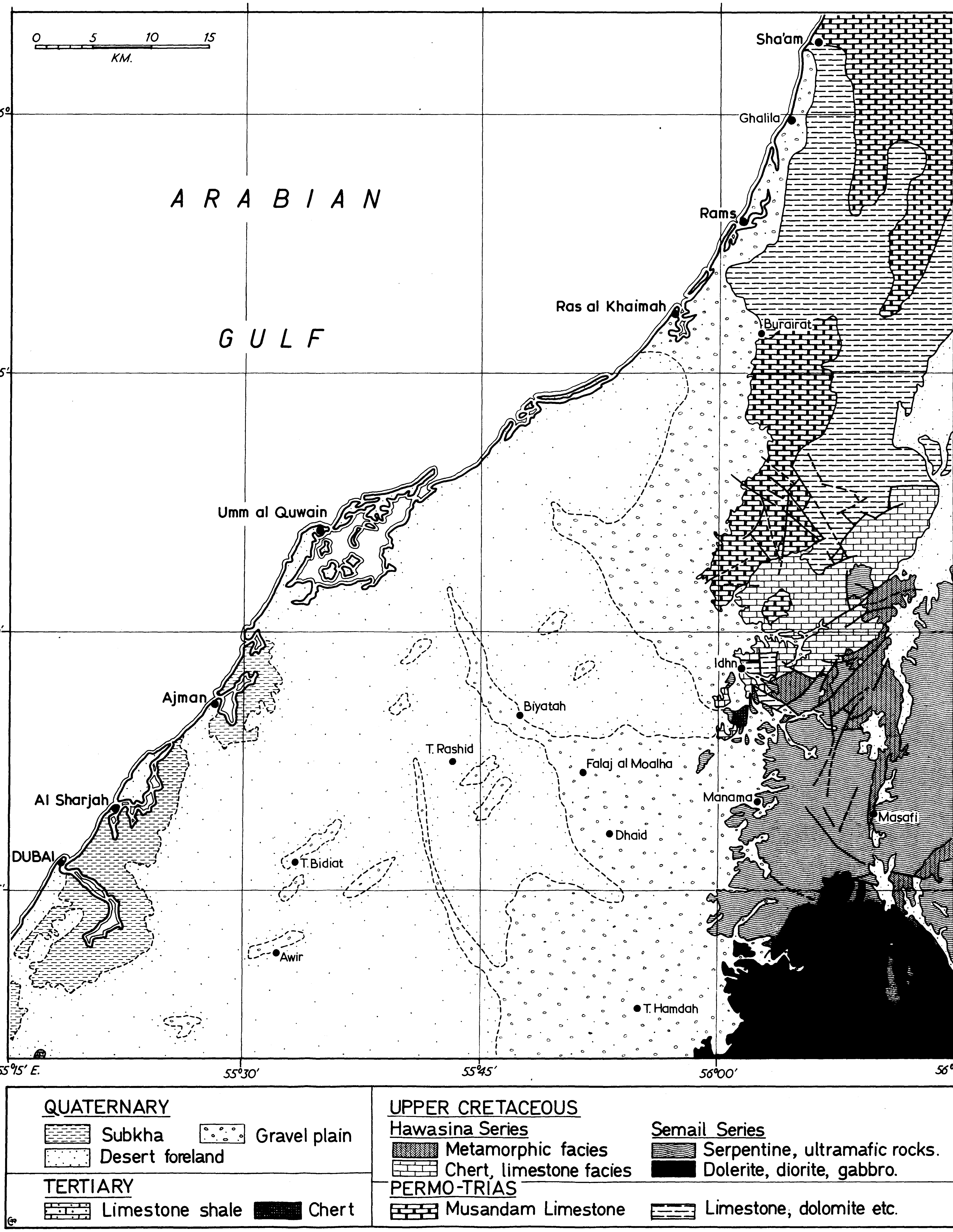
GRAVEL PLAIN (SOUTH) (continued)	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
T. Yafr 03857 27973	2.4.67	1450 1463	980	8·5	391	274	33 1·65 10·54	75 6·17 39·42	175 7·61 48·63	8·5 0·22 1·41	15·65	nil	335 5·49 33·25	170 3·54 21·44	260 7·33 44·40	7·1 0·12 0·73	0·5 0·03 0·18	16·51	0·06	0·01	0·11
T. Muraqibat 03892 28011	7.6.67	1260 1224	798	7·3	223	255	28·5 1·42 12·34	27 2·22 19·29	175 7·61 66·12	10·0 0·26 2·26	11·51	nil -	311 5·10 36·64	158 3·29 23·64	170 4·79 34·41	44 0·71 5·10	0·5 0·03 0·22	13·92	0·02	nil	0·08
HTS Dhaid 9	24.6.75	1000	720	7·0	-	-	29·0 1·45 14·56	56·5 4·65 46·67	85·1 3·70 37·15	6·3 0·16 1·61	9·96	nil -	207·4 3·40 33·83	78·3 1·63 16·22	178·0 5·02 49·95	-	-	10·05	-	-	-
" " 10	2.4.75	850	620	7·4	-	-	21·0 1·05 12·30	44·4 3·65 42·74	85·1 3·70 43·33	5·5 0·14 1·64	8·54	nil -	219·7 3·60 42·50	60·5 1·26 14·88	128·0 3·61 42·62	-	-	8·47	-	-	-
" " 56	26.6.75	800	600	7·5	-	-	21·0 1·05 13·44	52·7 4·33 55·44	53·6 2·33 29·83	3·9 0·10 1·28	7·81	nil -	163·5 2·68 34·99	33·6 0·70 9·14	151·8 4·28 55·87	-	-	7·66	-	-	-
" " 75	26.8.75	660	460	7·6	-	-	16·0 0·80 12·80	32·2 2·65 42·40	61·6 2·68 42·88	4·7 0·12 1·92	6·25	nil -	193·4 3·17 51·05	28·8 0·60 9·66	86·5 2·44 39·29	-	-	6·21	-	-	-
" " 78	22.6.75	860	610	8·3	-	-	21·0 1·05 12·47	46·2 3·80 45·13	79·3 3·45 40·97	4·7 0·12 1·43	8·42	14·4 0·48 5·65	174·5 2·86 33·65	48·0 1·00 11·76	147·5 4·16 48·94	-	-	8·50	-	-	-
" " 80	22.8.75	680	480	8·4	-	-	16·0 0·80 11·80	36·2 2·98 43.95	66·2 2·88 42·48	4·7 0·12 1·77	6·78	18·0 0·60 8·85	172·7 2·83 41·74	28·8 0·60 8·85	97·5 2·75 40·56	-	-	6·78	-	-	-
" " 82	22.6.75	750	520	8·2	-	-	17·0 0·85 11·50	40·5 3·33 45·06	70·8 3·08 41·68	5·1 0·13 1·76	7·39	12·6 0·42 5·71	175·1 2·87 39·05	33·6 0·70 9·52	119·2 3·36 45·71	-	-	7·35	-	-	-

9

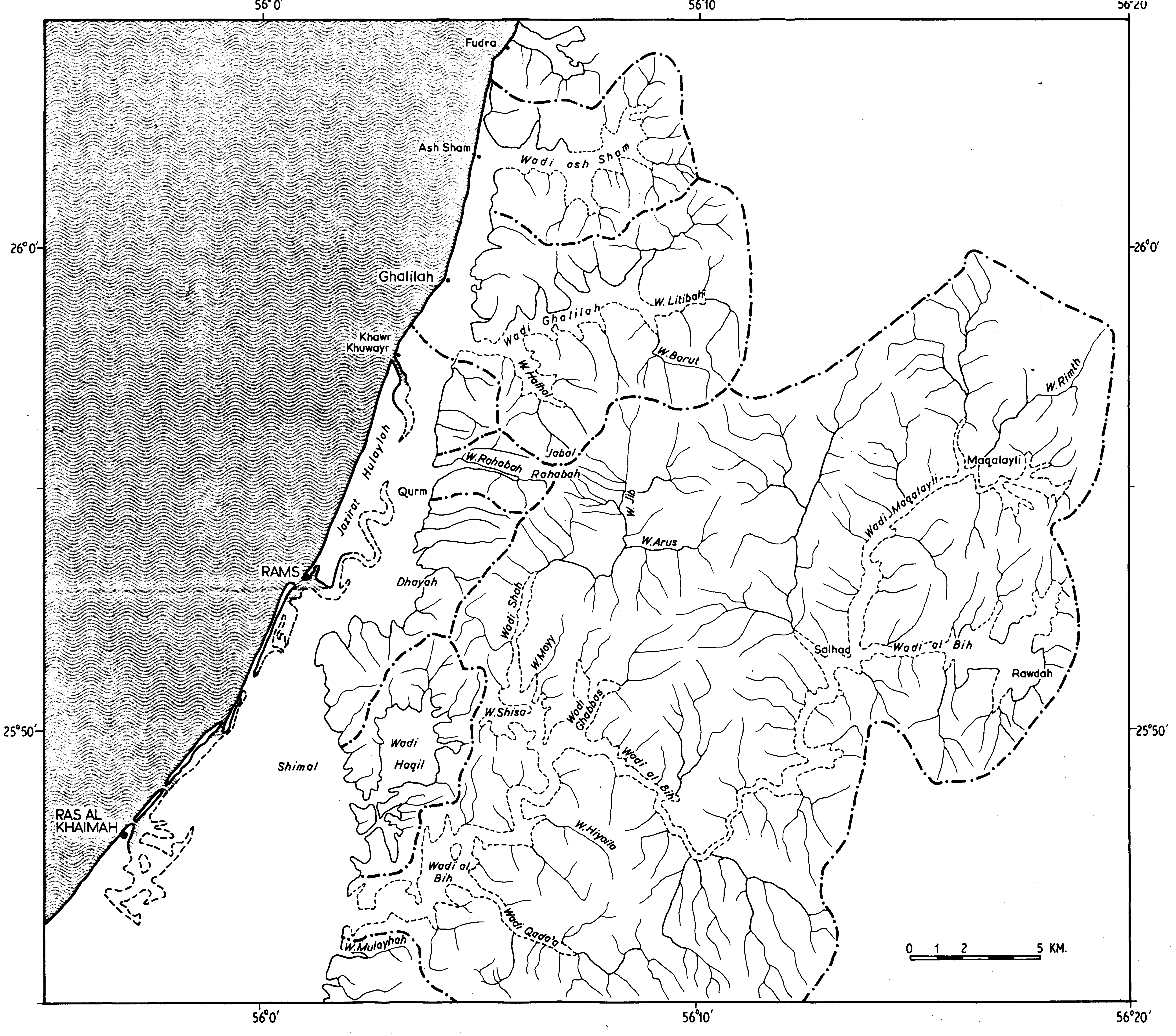
GRAVEL PLAIN (SOUTH) (continued)	Date	EC	TDS	pH	Hard	Alk.	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
HTS Dhaid 85	30.6.75	900	640	7·9	-	-	22·0 1·10 12.32	38·3 3·15 35·27	103·5 4·50 50·39	7·0 0·18 2·02	8·93	10·2 0·34 3·79	225·1 3.69 41·09	76·9 1·60 17·82	118·8 3·35 37·31	-	-	8·98	-	-	-
" " 88	30.6.75	2000	1340	8·3	-	-	33·7 1·68 8·66	50·5 4·15 21·40	308·1 13·40 69·11	6·3 0·16 0·83	19·39	30·0 1·00 5·05	221·5 3·63 18·33	158·5 3·30 16·67	420·9 11·87 59·95	-	-	19·80	-	-	-
" " 123	9.7.75	1200	820	7·9	-	-	24·1 1·20 10·04	50·5 4·15 34·73	148·3 6·45 53·97	5·9 0·15 1·26	11·95	9·0 0·30 2·46	230·0 3·77 30·93	96·1 2·00 16·41	217·0 6·12 50·21	-	-	12·19	-	-	-
" " 162a	26.8.75	900	640	7·8	-	-	22·0 1·10 12·02	54·5 4·48 48·96	79·3 3·45 37·70	4·7 0·12 1·31	9·15	6·0 0·20 2·19	180·6 2·96 32·39	76·9 1·60 17·51	155·3 4·38 47·92	-	-	9·14	-	-	-
" " TW2	12.8.75	760	530	8·4	-	-	14·0 0·70 8·96	32·2 2·65 33·93	99·5 4·33 55·44	5·1 0·13 1·66	7·81	30·0 1·00 12·17	213·6 3·50 42.58	40·4 0·84 10·22	102·1 2·88 35·04	-	-	8·22	-	-	-
" " TW3	23.8.75	1060	730	8·0	-	-	20·0 1·00 10·19	16·8 1·38 14·07	160·9 7·00 71·36	16·8 0·43 4·38	9·81	12·0 0·40 3·91	220·9 3·62 35·42	68·7 1·43 13·99	169·2 4·77 46·67	-	-	10·22	-	-	-
" " A2	13.6.75	1140	760	8·5	-	-	16·0 0·80 7·33	27·1 2·33 20·42	178·2 7·75 70·97	5·5 0·14 1·28	10·92	39·0 1·30 10·99	195·2 3·20 27·05	84·5 1·76 14·88	197·5 5·57 47·03	-	-	11·83	-	-	-

Location MOUNTAINS	Date	EC	TDS	pH	Hard	Alk	Ca	Mg	Na	K	Σ Cat.	CO_3	HCO_3	SO_4	Cl	NO_3	F	Σ An.	Fe	Mn	B
47 Ein Masifi 04158 27992	21.11.66	392 372	262	8·2	190	100	8·2 0·41 9·5	41·1 3·38 78·4	11 0.48 11·1	1·5 0·04 0·9	4·31	- - -	121 1·98 43·0	48 1·00 21·7	45 1·27 27·6	22 0·35 7.6	Tr - -	4·60	0·13	nil	0·04
116 Idhu 04008 28152	13.4.67	1280 1330	838	8·4	343	213	28·5 1·42 10·5	66·0 5·43 40·1	150 6·53 48·2	6·5 0·17 1·3	13·55	- - -	260 4·26 29·5	170 3·54 24·5	230 6·49 45·0	6·9 0·11 0·8	0·5 0·03 0·2	14·43	0·02	0·01	0·22
51 Idhu 04003 28156	13.11.66	1740 1410	1096	8·5	421	254	42·3 2·11 12·0	76·5 6·29 35·9	204 8·87 50·6	9·8 0·25 1·4	17·52	- - -	309 5.06 28·4	116 2·42 13·6	362 10·21 57·3	8·0 0·13 0·7	Tr - -	17·82	0·11	nil	0·02
33 Masafi 04159 27983	28.9.66	610 439	306	8·6	151	115	8 0·40 7·0	31·5 2·59 45·0	61 2·65 46·1	4·3 0·11 1·9	5·75	12 0·40 6·9	116 1·90 32·8	9 0·19 3·3	117 3·30 57·0	- - -	Tr - -	5·79	0·27	0·04	0·08
34 Masafi 04159 27983	30.9.66	670 490	349	8·7	103	103	9·6 0·48 7·9	19·2 1·58 25·9	90 3·92 64·4	4·3 0·11 1·8	6·09	30 1.00 16·6	65 1·07 17·7	4 0·08 1·3	138 3·89 64·4	- - -	Tr - -	6·04	0·09	0·03	0·02
118 Masafi 04159 27983	16.2.67	-	600	10·4	45	100	4·8 0·24 3·7	7·8 0·64 10·0	124 5·39 84·1	5·6 0·14 2·2	6·41	- -	- - (incomplete)	24 0·50	142 4·00	- -	- -	4·5*	-	-	-
52 Masafi 04163 27983	1.11.66	475 366	326	7·1	169	84	6 0·30 6·8	37·2 3·06 69·6	23 1.00 22·7	1·5 0·04 0·9	4·40	- - -	102 1·67 38·0	43 0·90 20·5	64 1·81 41·2	0·4 0·01 0·1	Tr - -	4·39	0·28	Tr	0·05

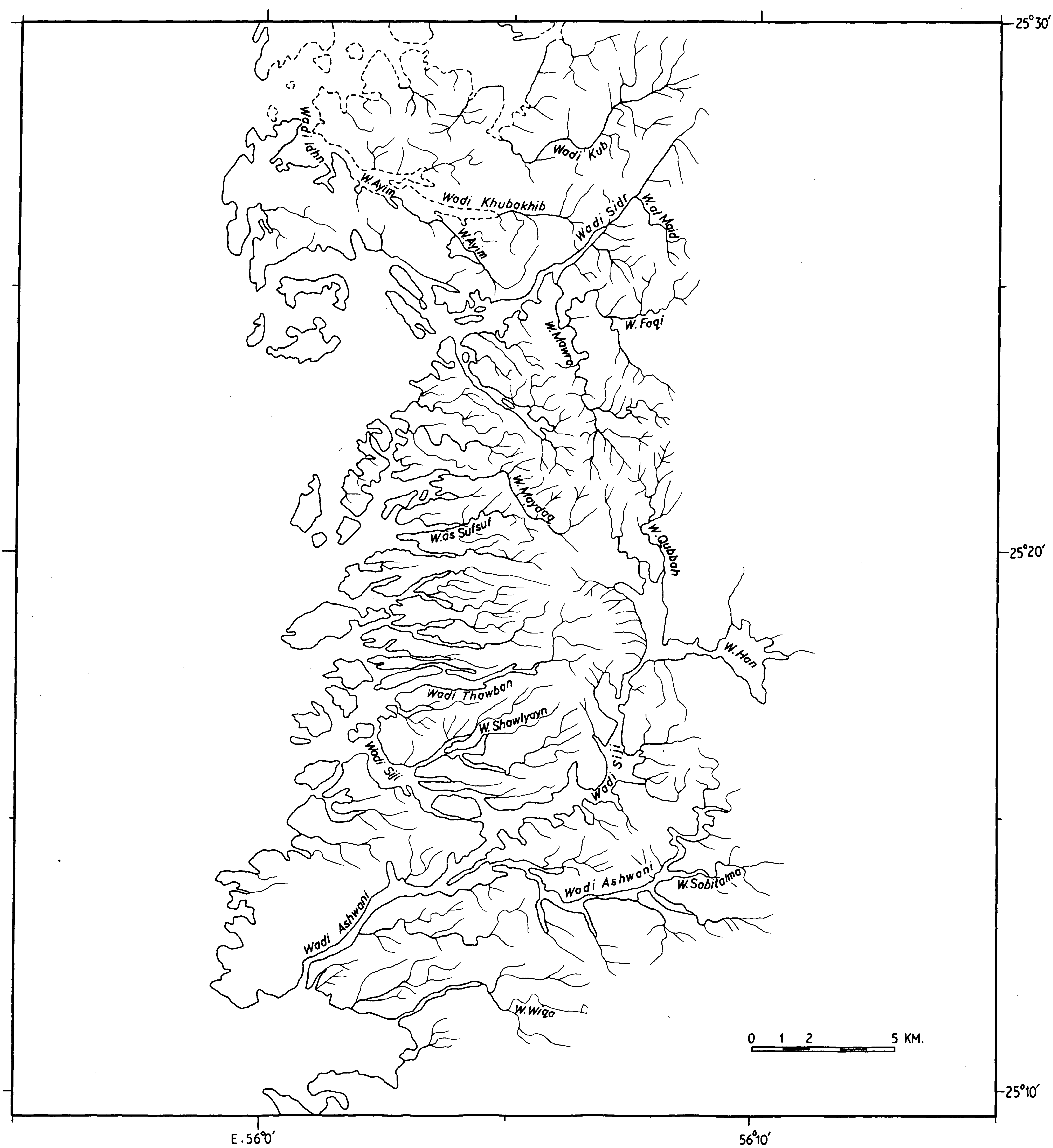
* incomplete analysis

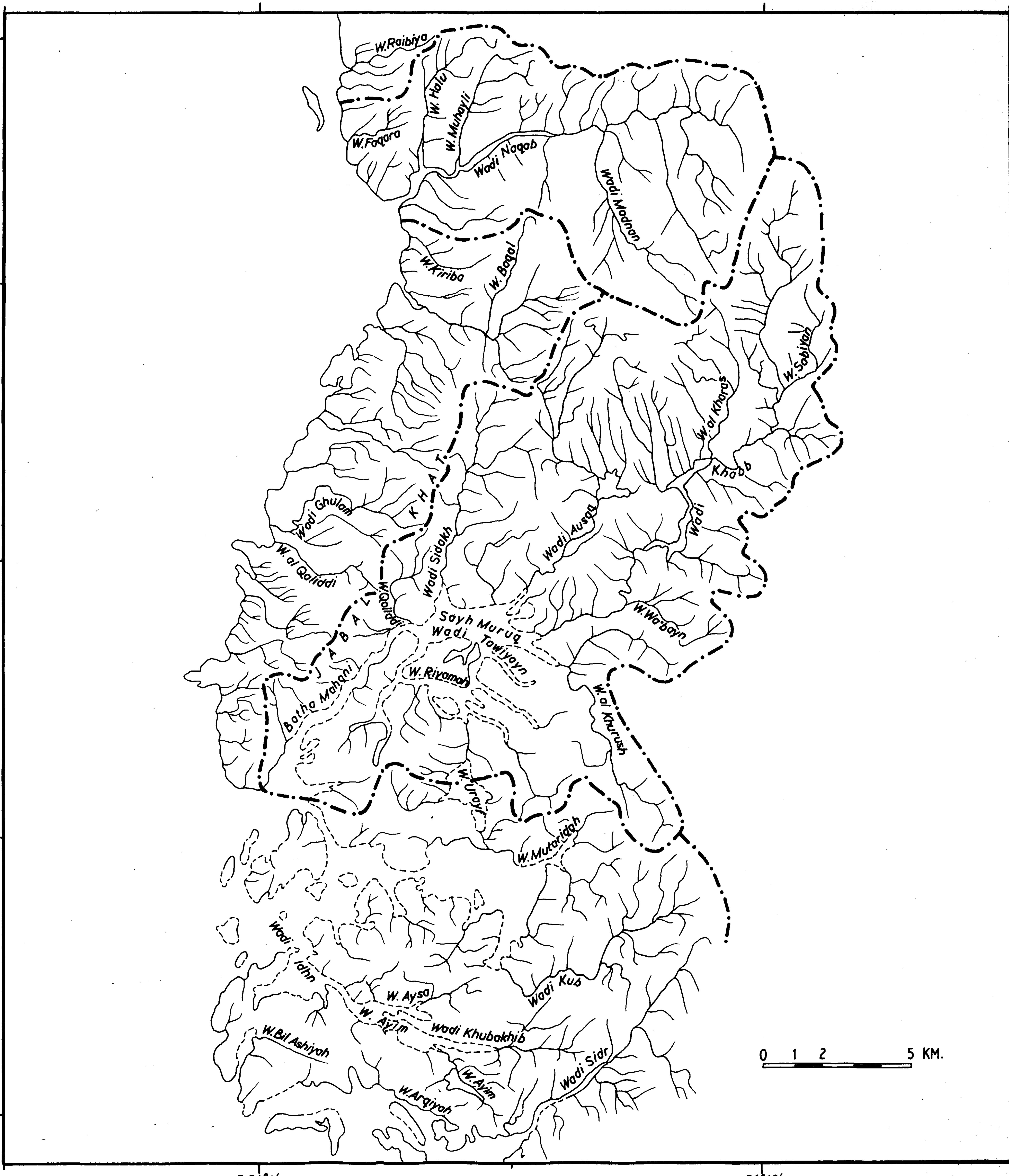


GEOLOGICAL MAP (based on I.G.S. and Hallcrow surveys)

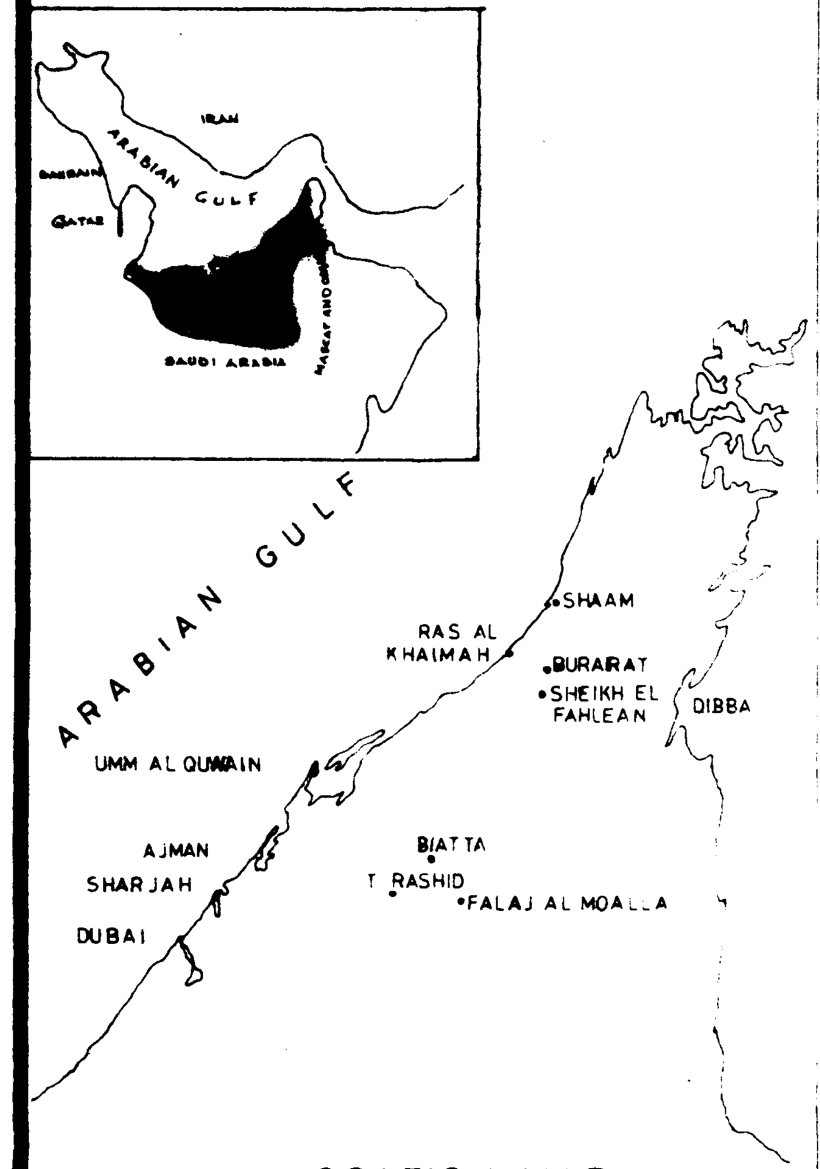


56°0′
56°10′
56°20′
26°0′
25°50′
Fudra
Ash Sham
Wadi ash Sham
Ghalilah
W. Litibah
Wadi Ghalilah
Khawr Khuwayr
W. Barut
W. Haihai
W. Rimth
Jabal
W. Rahabah
Rahabah
Hulaylah
Qurm
W. Jib
Maqalayli
Wadi Maqalayli
Jazirat
W. Arus
RAMS
Dhayah
Wadi Shah
W. Mayy
Salhad
Wadi al Bih
Rawdah
W. Shisa
Wadi Ghabbas
Wadi Haqil
Shimal
Wadi al Bih
RAS AL KHAIMAH
W. Hiyaila
Wadi al Bih
Wadi Qada'a
W. Mulayhah
0 1 2 5 KM.


25°30′
25°20′
25°10′
E. 56°0′
56°10′
Wadi Idhn
W. Ayim
Wadi Khubakhib
Wadi Kub
Wadi Sidr
W. al Maid
W. Ayim
W. Faqi
W. Mawra
W. Maydaq
W. as Sufsuf
W. Qubbah
W. Han
Wadi Thowban
W. Shawlyayn
Wadi Siji
Wadi Siji
Wadi Ashwani
W. Sobitalma
Wadi Ashwani
W. Wiqa
0 1 2 5 KM.


W. Raibiya
W. Halu
W. Muhayli
W. Faqara
Wadi Naqab
Wadi Madhan
W. Kiriba
W. Baqal
W. Sabiyan
W. al Kharas
Khabb
Wadi
Wadi Ghulam
K H A T
Wadi Sidakh
Wadi Ausqa
W. al Qaliddi
W. Qaliddi
J A B A L
Sayh Muruq
Wadi Tawiyayn
W. Wa'bayn
W. Riyamah
Batha Mahani
W. al Khurush
W. Urayf
W. Mutariqah
Wadi Idhn
Wadi Kub
W. Aysa
W. Ayim
Wadi Khubokhib
W. Bil Ashiyah
Wadi Sidr
W. Ayim
W. Arqiyah
0 1 2 5 KM.
25°40′
25°30′
E.56°0′
56°10′

LITHOLOGICAL LOGS REPRESENTING THE MAIN WATER SUPPLY AREA



LOCATION MAP

LITHOLOGICAL INDEX

GRAVELS

COARSE TO VERY COARSE SAND

FINE SAND

CLAY

SHAAM

0-0": GRAVELS - Dark grey, angular to subangular with rare patches of brownish grey

185-0"

TOTAL DEPTH 185'-0"

WELL NO 2 SHAAM (Ras al Khaimah Government)

Starting Date:	2nd November 1976.
Completion Date:	6th November 1976.
Total Depth:	185 Feet.
Casing:	Plain 10 inch diameter P.V.C. 125 feet.
Screens:	10 inch diameter P. V. C. 60 feet.
Formation:	Gravels (alluvial deposit)
Duration of pump test:	24 hours - Output 60 m^3
Maximum Drawdown:	1.40 m
Discharge:	13200 g/h

BURAIRAT

0 – 50 metres

0-0: GRAVELS Dark grey, angular

10-5: GRAVELS Dark and light grey, rare white, angular.

50-0: GRAVELS Dark gray, angular

70-0: GRAVELS Light and dark grey, rare brown angular.

100-0: GRAVELS: Blackish grey, grey and dark brown, angular.

120-0: GRAVELS: Dark grey, little light grey and brown, angular.

150-0: GRAVELS: Dark grey rare brownish grey, angular.

160-0: GRAVELS: Dark and light grey, rare whitish grey, angular.

190-0: GRAVELS. Dark and light grey, rare brownish grey, angular.

220-0: GRAVELS: Dark and brownish grey, angular.

250-0

TOTAL DEPTH 250-0

RAS AL KHAIMAH WELL NO 4 BURAIRAT

Site and well no.	Burairat Well No. 4.
Drilling Started Date.	14-5-1976.
Drilling Completion Date.	18-5-1976.
Total Depth.	250 Feet.
Casing From	0 to 188 Feet.
Screens From	188 to 250 Feet.
Mean discharge per hour (Q)	30,960 m^3/h
Static Water Level	53.10 metres
Maximum Drawdown	3.61 metres

SEIKH EL FAHLEAN

0-0: SAND: Gravels, dark and light grey angular, whitish grey, rare pink

50-0: SAND Gravels, light and dark grey little black, angular, rare whitish gray and pink

100-0: SAND: Very coarse, angular.

110-0: SAND: Gravels light and dark grey little pink and whitish grey angular

140-0: SAND: Very coarse and coarse grains with gravels, dark and light gray, brown, black.

160-0: SAND: Gravels brown grey, whitish gray.

170-0: SAND: Gravels very coarse graind

180-0: SAND Gravels dark and light grey, smoky, rare pink, angular grained

200-0

TOTAL DEPTH 200-0"

WELL NO. 1 SHEIKH EL FAHLEAN

Starting Date:	7th June 1976.
Completion Date:	12th June 1976.
Static Water Level:	22.48 m
Casing:	14 inch diameter – 140 ft.
Screens:	10 inch diameter Stainless Steel – 60 ft.
Total Depth:	200 ft.
Airlift Test:	6 hours Output 13,000 g/h
Pump Test:	48 hours Output 90 m^3/h

BIATTA

0-0: SAND: Gravels, dark brown with few grains, light brown, subangular to subrounded.

90-0: SAND: Gravels, dark and light brown, subrounded.

100-0: SAND: White, coarse to gravels, subrounded, few grains, dark brown

120-0: SAND: Gravels. white. subrounded, with few dark brown grains.

150-0

TOTAL DEPTH 150-0"

WELL NO. 2 BIATTA

Starting Date:	15th September 1976.
Completion Date:	23rd September 1976.
Total Depth:	150'0"
Casing:	Plain 12 inch diameter, 70 feet.
Screens:	10 inch diameter, Jhonson type – 80 feet.
Static Water Level:	17.52 m.
Total Drawdown:	26.48 m.
Duration of Pump Test:	48 hours.

TAWI RASHID

0-0: SAND: Fine grain light yellowish brown.

10-0: SAND: fine grained, dark yellowish brown, loose.

180-0: SAND: Coarsed grained, white with black grains, subangular.

200-0

TOTAL DEPTH 200' 0"

WELL NO. 4 TAWI RASHID

Starting Date:	14th July 1976.
Completed Dated:	28th July 1976.
Total Depth:	205 Feet.
Plain Casing	120 feet, 12".
Screens.	80 feet 10" Johnson.
S. W. L.:	40.13 mrs.
Total Drawdown.	9.39 mrs.
Duration of Pump Test:	48 hours.

FALAJ AL MOALLA

0-0: SAND: Dark brown with little white sand grains, fine to coarse grained.

50-0: SAND: Dark brown, gravel size, little white grains.

70-0: CLAY: Light brown and grey. cuttings are angular, gravel size.

90-0: SANDY CLAY: Light brown with few dark brown grains.

160-0: SAND: Light brown smoky quartz, fine to gravels, grains all sub-angulars.

205-0

TOTAL DEPTH 205' 0"

WELL NO. 4 FALAJ AL MOALLA

Starting Date:	20th October 1976.
Completion Date:	27th October 1976.
Total Depth:	205 feet.
Casing:	Plain 12 inch diameter 60 feet.
Screens:	10 inch diameter. Johnson type – 80 feet.
Static Water Level:	20.13 m.
Total Dradown:	16.10 m.
Discharge Expected:	3000 to 4000 g/h.
Duration of Pump Test:	24 1/2 hours.